

# **A STUDY OF CIRCLE OF WILLIS WITH ITS VARIATIONS AND ITS CLINICAL CORRELATIONS**

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CHENNAI – 600 001.**



**THE TAMILNADU DR. M.G.R. MEDICAL UNIVERSITY  
CHENNAI**

**APRIL 2018**

## **CERTIFICATE**

This is to certify that the dissertation work on “**A STUDY OF CIRCLE OF WILLIS WITH ITS VARIATIONS AND ITS CLINICAL CORRELATIONS**” is a bonafide research work done by **Dr. V. SHANTHI**, post graduate (2015-2018) in the Department of Anatomy, Govt. Stanley Medical College and Hospital, Chennai under my direct guidance and supervision, in partial fulfillment of the regulations laid down by the TAMILNADU DR. M.G.R. MEDICAL UNIVERSITY Chennai for the award of M.D. Anatomy (Branch XXIII) degree examination to be held in APRIL 2018.

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## DECLARATION

I hereby declare that this dissertation entitled in “**A STUDY OF CIRCLE OF WILLIS WITH ITS VARIATIONS AND ITS CLINICAL CORRELATIONS**” was written by me in the Department of Anatomy, Government Stanley Medical College and Hospital, Chennai under the guidance and supervision of **Prof. Dr. T. VASANATHA KUMAR, M.S.**, Professor and Head of the Department of Anatomy, Government Stanley Medical College and Chennai – 600 001.

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The request for an approval from the Institutional Ethical Committee (IEC) was considered on the IEC meeting held on 14.06.2016 at the Council Hall, Stanley Medical College, Chennai-1 at 2PM

The members of the Committee, the secretary and the Chairman are pleased to approve the proposed work mentioned above, submitted by the principal investigator.

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# INTRODUCTION

The brain is a vital organ which requires rich blood supply to sustain its ongoing activities. Irreversible brain damage occurs when the blood supply is interrupted for few minutes, which results in loss of consciousness **(Neeta Kulkarni 3<sup>rd</sup> edit)**. Approximately 15% of the total blood supply reaches the brain and approximately 20% of the oxygen utilization is consumed by the adult brain **(Parthapratim Pradhan et al 2009)**. The blood flow to the brain is estimated to be around 800ml/min of brain tissue. The blood flow is faster in the grey matter (70-80ml/100g/min) than in white matter (30ml/100g/min). Blood flow of less than 15ml/100g/min leads to irreversible brain damage **(Gray's Anatomy edit 40<sup>th</sup>)**.

The brain receives its blood supply from four arterial trunks, two internal carotid arteries and two vertebral arteries. The internal carotid artery arises from the common carotid artery at the level of upper border of thyroid cartilage. The vertebral artery is a branch of first part of subclavian artery **(Ranganathan T.S edit 3rd )**.

The Circle of Willis is a large arterial anastomosis which unites the internal carotid artery and vertebral artery. It is named after Thomas Willis, an English physician **(Shane Tubb 2013, Willis T, 1664)**. Both

the arteries together with their branches lie within the subarachnoid space called interpeduncular cistern at the base of the brain. It is a ring like network of blood vessels which is essential for the perfusion of brain. The two internal carotid arteries contribute 80% of the blood supply to the brain and the two vertebral arteries contribute 20% of the blood supply (**Grand W 1999**). Each of the internal carotid artery branches to form anterior and middle cerebral arteries which supply blood to the brain. The ring is completed by the communicating arteries which connect the anterior and posterior part of the circle. In about 60% of cases, anatomical variations in the Circle of Willis may be found (**Battacharji SK 1967, Craig Hacking**).

The anterior communicating artery and the posterior communicating arteries are the component vessels of the Circle of Willis and designated as the primary collateral pathways. Other pathways such as reversal of flow through the ophthalmic artery, anterior choroidal artery and the anastomosis between the cortical branches of the intracerebral arteries are considered as secondary collaterals (**Shankar Rao Naveen 2015**). In case of abnormality in the Circle of Willis, these collaterals become main anastomotic channels. The collaterals of Circle of Willis depend upon the presence and size of its component vessels (**Iqbal S 2013**).

Under normal condition, the blood flow in the communicating arteries are negligible. If a subject has an atypical circle (missing of one of the main artery or the communicating artery) or under pathological condition (partial or complete occlusion of cerebral or carotid vessels), the flow can be redirected to perfuse deprived areas (**Vare AM 1970**). It has been found that in 50% of the normal brain and in 80% of the dysfunctional brain, the Circle of Willis is often incomplete or underdeveloped. The most common morphological variations are absent vessels, hypoplastic vessels and extra vessels (**Neeta Kulkarni edit 3<sup>rd</sup>** ).

These variations affect the ability to maintain the blood flow through arterioles, which may increase the risk of stroke and transient ischemic attack in atherosclerotic patients (**Riggs HE1963**). Acute occlusion due to embolus (embolic stroke) or chronic occlusion due to stenosis of anyone of the vessel (carotid and other large vessel stenosis) occurs in patients with incomplete Circle of Willis (**Alpers 1959**). These problems are significant, as stroke is one of the leading cause of morbidity and death in elderly people.

A sound knowledge about the anatomy of the Circle of Willis and its possible variations are essential for clinicians, vascular surgeons and radiologists. This will help them to understand most of the cerebrovascular diseases and to do current diagnostic and therapeutic

procedures and also in interpreting Computerized Tomography and Magnetic Resonance Imaging pictures (**AyseKaratas 2015**).

# ANATOMICAL AND EMBRYOLOGICAL CONSIDERATIONS

The Circle of Willis is one of the principal arterial anastomosis of the brain. It is formed by the anastomosis between the branches of cerebral part (supraclinoid part) of right and left internal carotid arteries and the terminal branches of basilar artery. Circle of Willis is responsible for brain's collateral blood supply (**Gray's Anatomy 40<sup>th</sup> edit**). Circle of Willis is composed of following arteries:

- Internal Carotid Artery (left and right).
- Anterior Cerebral Artery (left and right).
- Anterior Communicating Artery.
- Posterior Cerebral Artery (left and right).
- Posterior Communicating Artery (left and right).

The Circle of Willis lies in the subarachnoid space within the interpeduncular cistern. It surrounds the optic chiasma and the infundibulum (**Raghavendran et al**). The right and left vertebral arteries arise from the first part of right and left subclavian arteries. The left and right internal carotid arteries arise from the left and right common carotid arteries (fig 1).



The left and right posterior cerebral arteries arise from the basilar artery, which in turn is formed by the union of fourth part of left and right vertebral arteries. The posterior communicating artery is given off as a branch of the internal carotid artery just before it divides into its terminal branches- the anterior and middle cerebral arteries. The anterior cerebral artery forms the anterolateral portion of the Circle of Willis, while the middle cerebral artery does not directly contribute to the circle. The two anterior cerebral arteries communicate with each other through the anterior communicating artery (Gray's Anatomy 40<sup>th</sup> edit).

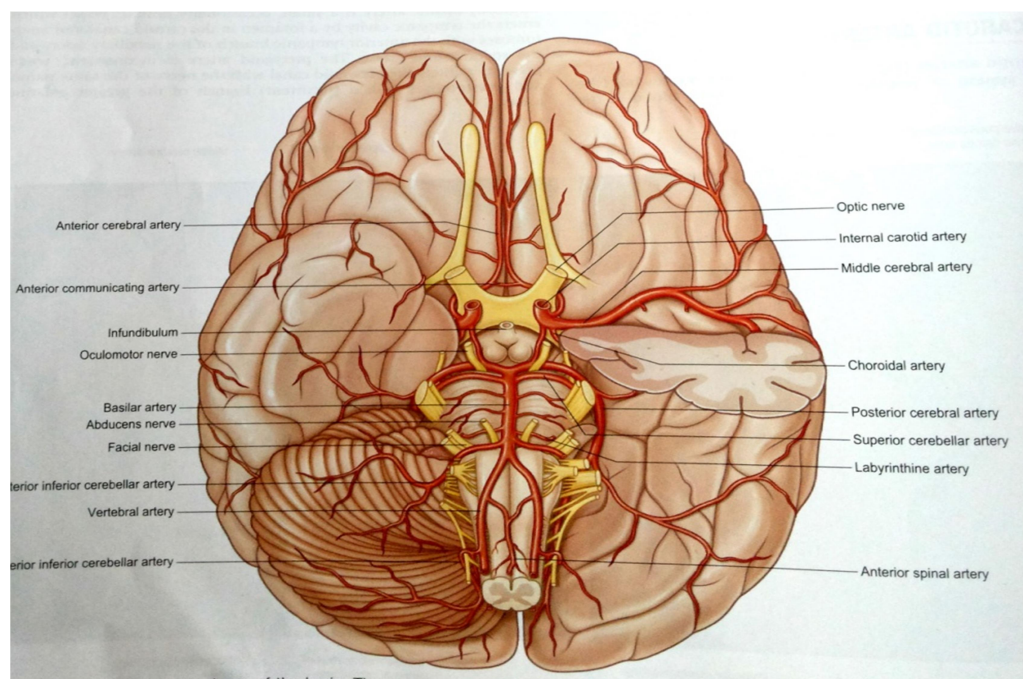


Fig 1. Showing Circle of Willis at the base of the brain.

The internal carotid arteries and their major branches (the internal carotid system or ‘anterior’ circulation) supply blood to the majority of the forebrain. The internal carotid artery arises from the bifurcation of the common carotid artery at the level of upper border of thyroid cartilage, ascends in the neck and enters the carotid canal of the temporal bone **(Romanes GJ Cunningham edit 15<sup>th</sup>)**.

Its subsequent course is said to have petrous, cavernous and intracranial part. The petrous part of the internal carotid artery ascends in the carotid canal, curves anteromedially and then superomedially above the cartilage that fills the foramen lacerum. It forms the anterior wall of the tympanic cavity and is separated from the tympanic cavity by a thin bony lamella that is cribriform in the young and partly filled in old age **(Ranganathan T.S edit 3<sup>rd</sup>)**. Anteriorly, it is separated from the trigeminal ganglion by the thin plate of carotid canal. The artery is surrounded by venous plexus and by the autonomic plexus derived from the internal carotid branch of superior cervical ganglion. The petrous part gives two branches, one or two small caroticotympanic arteries and pterygoid artery **(Gray’s Anatomy 40<sup>th</sup> edit)**.

The cavernous part of the internal carotid artery ascends to the posterior clinoid process, turns anteriorly within the cavernous sinus and then curves up medially to the anterior clinoid process and emerges

through the dural roof of the sinus. The oculomotor, trochlear, ophthalmic and maxillary nerves are lateral to internal carotid artery within the lateral wall of cavernous sinus (**Kamath S 1981**) (fig 2). The cavernous part gives off small meningeal, cavernous, and inferior hypophyseal branches.

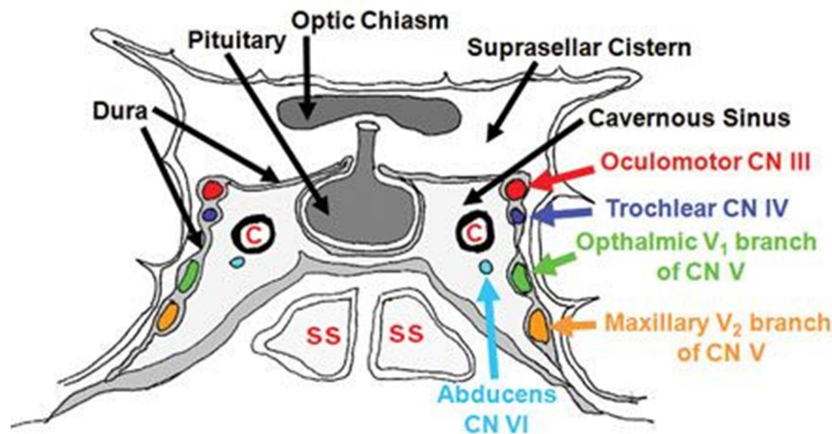


Fig 2 : Relation of internal carotid artery in cavernous sinus.

The internal carotid artery after piercing the duramater turns back below the optic nerve and gives off superior hypophyseal artery, runs between the optic nerve and the oculomotor nerve. It reaches the anterior perforated substance at the medial end of the lateral fissure. It terminates by dividing into anterior and middle cerebral arteries (**Cunningham manual edit 15<sup>th</sup>**).

## **ANTERIOR CEREBRAL ARTERY:**

The anterior cerebral artery is the smaller of the two terminal branches of the internal carotid arteries. According to **Ranil De Silva 2016** Surgical nomenclature divides the vessel into three parts. A1-from the termination of internal carotid artery to the junction with the anterior communicating artery; A2-from the junction with the anterior communicating artery to the origin of callosomarginal artery; A3-distal to the origin of callosomarginal artery(**fig 3**).

- The cortical branches supply the orbital surface of the frontal lobe and supply the olfactory cortex, gyrus rectus and medial orbital gyrus. They also supply the motor and somatosensory areas that represent the lower limb.
- Frontal branches supply the corpus callosum, cingulate gyrus and paracentral lobule.
- Parietal branches supply the precuneus and the surrounding areas.
- Central branches supply the rostrum of corpus callosum, the septum pellucidum, anterior part of the putamen, head of the caudate nucleus and adjacent parts of the internal capsule (**Gardner E et al 1969**).

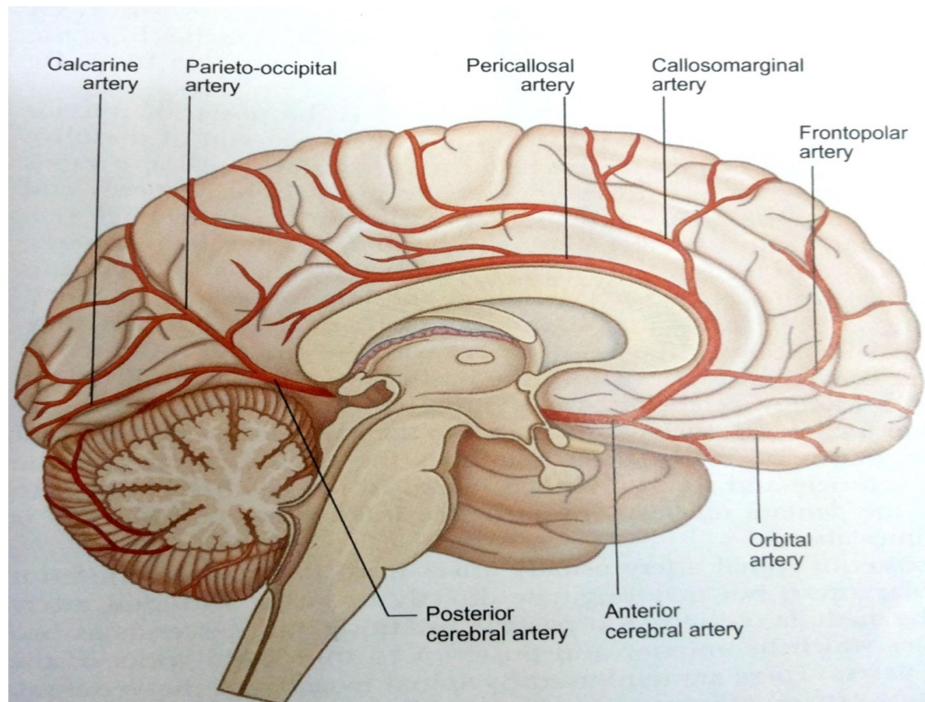


Fig 3: showing the course of anterior cerebral artery.

### **MIDDLE CEREBRAL ARTERY:**

The middle cerebral artery is the larger terminal branch of the internal carotid artery. It divides into four parts.

- M1-from the termination of the internal carotid artery to its bifurcation. This is known as sphenoidal segment.
- M2 segment - running in the lateral (sylvian) fissure, also known as the insular or sylvian segment.
- M3 segment- extends laterally from insula towards the cortex and is known as opercular part.
- M4 terminal or-cortical portions.

The middle cerebral artery runs at first in the lateral fissure, then posterosuperiorly on the insula and divides into branches. Middle cerebral artery gives off cortical and central branches (**Vaibhav V 2016**).

#### **VERTEBRAL ARTERY:**

The right and left vertebral arteries are derived from the first part of respective subclavian arteries, ascend through the neck in the foramina transversoria of the upper six cervical vertebrae and enter the cranial cavity through the foramen magnum close to the anterolateral aspect of the medulla. They converge medially and unite to form the basilar artery at the pontomedullary junction (**Cunninghams manual 15<sup>th</sup> edit**).

#### **BASILAR ARTERY:**

Basilar artery is a large median vessel formed by the union of the right and left vertebral arteries at the mid medullary level. It lies in the pontine cistern and follows the shallow median groove on the ventral pontine surface, extending to the upper border of the pons. It ends by dividing into right and left posterior cerebral arteries at a variable level behind the dorsum sellae, usually in the interpeduncular cistern (**Mamatha H 2012**) (fig4).

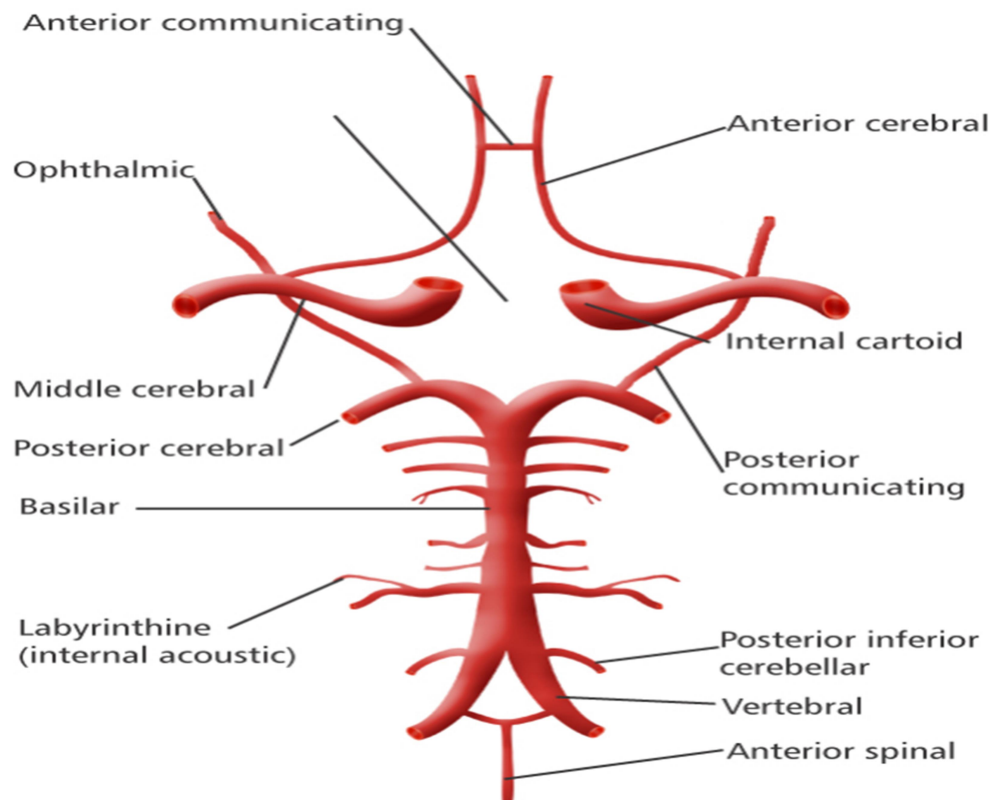


Fig 4:showing the vertebral and basilar network.

### **POSTERIOR CEREBRAL ARTERY:**

The posterior cerebral artery is a terminal branch of the basilar artery. Surgical nomenclature divides into three parts (**Ace Dodevski et al 2014**).

- P1-from the basilar bifurcation to the junction with the posterior communicating artery.
- P2-from the junction with the posterior communicating artery to the portion in the perimesencephalic cistern.

- P3-the portion that runs in the calcarine fissure. The cortical branches supply the temporal, parieto-occipital lobes of the brain, the central branches supply the subcortical structures.

### **ANTERIOR COMMUNICATING ARTERY:**

Anterior communicating artery is about 4mm in length and it connects the two anterior cerebral arteries.

### **POSTERIOR COMMUNICATING ARTERY:**

The posterior communicating arteries are usually very small, arising from the internal carotid artery at the junction where it divides into anterior and middle cerebral arteries. Sometimes it is so large that the posterior cerebral artery is supplied via the posterior communicating artery rather than from the basilar artery (fetal posterior communicating artery) (Anuba Saha et al 2013)

### **EMBRYOLOGICAL CONSIDERATION:**

The vascular system develops in two stages: Vasculogenesis and Angiogenesis. The embryological development of the circulatory system supplying blood to the brain begins with the formation of the six pairs of primitive branchial arteries at the 1.3mm embryonic stage (BattacharjiSk 1967).



The brain vascular system arises from the perineural vascular plexus which sprout radially into the neuroepithelium. They subsequently branch off laterally in the subventricular zone, the subventricular plexus **(Mall FP 1905)**. *Foxc1* gene is required for early stage telencephalic vascular development as it is expressed in endothelial cells and pericytes, as well as in the cranial mesenchyme surrounding the brain tube **(Streeter GL)**.

Most of the branches of the Circle of Willis are derived from the internal carotid artery which is embryologically formed from the third arch artery distal to the external carotid bud and cranial part of the dorsal aorta distal to the attachment of third arch artery **(Langman embryology 12th edit)**. The ventral portion of the 2<sup>nd</sup> branchial artery disconnects from the dorsal aorta near the origin of the internal carotid artery and becomes the ventral pharyngeal artery. Then the ventral pharyngeal and the internal carotid artery fuse to form the common carotid artery.

At the 4mm stage, the internal carotid artery branches off into anterior and posterior divisions. The anterior division gives rise to the anterior cerebral artery(ACA), middle cerebral artery(MCA) and anterior choroidal artery. The posterior division gives rise to posterior cerebral artery (PCA) and the posterior choroidal artery.

The vertebral artery is a composite vessel and it is developed from four sources (**Mall FP 1905**).

- The first part of the artery develops from the dorsal ramus of the intersegmental artery.
- The second part of the artery develops from the enlargement of the post-costal anastomosis with the consequent regression of the stems of the upper six intersegmental arteries.
- The third part of the artery develops from the spinal branch of the first cervical intersegmental artery.
- The fourth part of the artery develops from the pre-neural division of the spinal branch which meets the corresponding branch of the opposite side at the caudal border of the pons to form the basilar artery.

The intracranial vertebrobasilar system develops after the internal carotid system. A number of segmental branches arise from the dorsal aorta supply the endodermal, ectodermal and mesodermal elements and supply the neural tube. Longitudinal anastomosis between the vessels gives rise to vertebral artery and because of its segmental nature, the vertebral artery is more prone to variations such as hypoplasia, fenestrations etc.

## AIM AND OBJECTIVES

The brain is richly supplied by blood through the vertebro-basilar and internal carotid arteries. The oxygen consumption of the neural tissue is very high (**Neeta Kulkarni 3<sup>rd</sup> edit**). Acute arrest of circulation produces loss of consciousness in about approximately seven seconds. The cerebrovascular accidents (CVA) due to infarction, hemorrhage and embolism result in stroke, in which the entire half of the body or a limb or one half of the face is suddenly paralyzed (**Klutmans et al 1999**).

According to **Kawther A 2007** ‘The persons with narrowing of cerebral arteries due to hypertension, atherosclerosis and diabetes are more prone to stroke’. The common causes of cerebral hemorrhage are aneurysms of major arteries, small arteriolar aneurysms due to hypertension and A-V malformations.

Anatomical variations in the Circle of Willis are more common. Under normal condition, the blood flow is redistributed to the ischemic area through the collateral circulation, but in pathological states like thrombo-embolism, aneurysms, there is failure of redistribution of blood flow. This leads to ischemia and necrosis of the affected area of the brain (**Iman Singh 2014**). Therefore the blood supply of the cerebral cortex and of internal capsule assumes a great importance. So a sound

knowledge of the formation of Circle of Willis and its variations are essential for proper diagnosis and treatment of the diseases (**Iqbal S 2013, Hendrikse J 2005**).

**AIM:**

- To study the normal pattern of Circle of Willis both morphologically and radiologically.
- To study the variations in the branching pattern of the Circle of Willis and to correlate it clinically.

**OBJECTIVES:**

1. To study the formation of the Circle of Willis under the following parameters in both morphological specimens and radiological images.
  - a. Complete or incomplete formation.
  - b. Shape of Circle of Willis.
  - c. Normal or abnormal caliber of vessels.
  - d. Symmetrical or asymmetrical formation.
2. To study the variations in the formation, branching pattern under the following parameters in both morphological and radiological images.
  - a. absent vessels

- b. hypoplasia
  - c. accessory vessels and
  - d. anomalous origin in both morphology and radiology.
3. To study the incidence of variation of individual vessels, anterior and posterior part of Circle of Willis.
  4. To study the clinical correlation of the Circle of Willis and to state its importance in cerebrovascular diseases.
  5. To compare the results of this study with the previous studies.

# REVIEW OF LITERATURE

## MORPHOLOGICAL STUDY:

1. The morphology of Circle of Willis dates back to **Hetrophilis**, who discovered a structure which he called 'Rete mirabile'. **Galen** stated that the carotid arteries run in the neck and form rete mirabile after they enter the cranial cavity. **Fallopious (1523-62)**, **Casseriuss (1561-1616)**, **Vesling (1598-1649)** also described the formation of Circle of Willis in their studies.
2. **Thomas Willis (1621-1675)** gave the correct description of Circle of Willis which supplies the brain and the surrounding structures.
3. According to **Gray's Anatomy 40<sup>th</sup> edit, 2016**) 60% show variations in the morphology of the Circle of Willis. Cerebral arteries and the communicating arteries, the anterior and the posterior may be absent, variably hypoplastic, double or even triple in number. The hemodynamic balance may be disturbed by variations in the caliber of the cerebral and the communicating arteries.
4. **Neeta Kulkarni 3<sup>rd</sup> edit (2016)** states that the Circle of Willis equalizes the pressure of the blood flow of the two sides of the

brain, because it is the main collateral channel of both sides. It provides an alternate channel if any one of the arteries forming the Circle of Willis is blocked.

**5. Cunningham manual of practical Anatomy 15th edit(1986)**

stated that the arterial circle extends from the superior border of the pons to the longitudinal fissure and lies mainly in the interpeduncular fossa. It forms a route through which the blood enters either through the internal carotid or the basilar artery and forms a collateral channel in the base of the brain. So it is very important to analyse the morphology of Circle of Willis before tying off the carotid artery during surgical interventions and investigational procedures.

## **FORMATION OF CIRCLE OF WILLIS:**

6. The formation of Circle of Willis has been studied by many authors under various parameters. This includes complete or incomplete form, shape of the circle, caliber and symmetry of the circle. The incidence of ‘text book ‘ type of Circle of Willis range from 5% to 72% (**Iqbal 2013**). The incidence of variations in the morphological pattern of the Circle of Willis has been reported by various authors. This includes **Kamath S -44%, Alpers et al-47.7%, Raja Reddy et al-46.7%, Stephen and John-48%, Macchi et al-59%, Hartkamp et al-58%.**

## **VARIATIONS IN THE FORMATION AND BRANCHING PATTERN OF THE VESSELS OF CIRCLE OF WILLIS:**

7. **E.Fawcett 1905** –The Circle of Willis: An examination of 700 specimens stated that the percentage of incomplete circle with asymmetrical and abnormal shape constitute 30.3% of the total specimens.
8. **Fetterman GH 1941** on this study “Anomalies of the Circle of Willis” stated that in 195 adult brain specimens, hypoplasia was the most common anomaly i.e., 23%. The posterior communicating



artery was more commonly found to be hypoplastic followed by P1 segment of posterior cerebral artery.

**9. Kamath S 1981** “Observation on the length and diameter of vessels forming the Circle of Willis” stated that hypoplasia was the more common variant among 100 fixed brain specimens. Abnormal narrow diameter occurred in 25 vessels of 24 circles and was most frequently seen in the posterior cerebral and posterior communicating arteries.

**10. Bernard J. Alpers et al** on their study “Circle of Willis in cerebral Vascular Disorders” stated that there is great variability in the normal configuration of the Circle of Willis. Among 350 normal brain specimens, normal circle were found in 52%. This study states that the collateral circulation appears to have greater significance in cerebral vascular disorders.

**11. Raghavendra et al** conducted morphological study on 50 adult brain specimens. Among the 50 specimens, 28 cases (56%) had a normal pattern of Circle of Willis and variants were present in remaining 22 cases (44%). Most common variation was observed on the left side and posterior communicating artery was found to be more variable in the study.

**12. RanilD. De Silva et al** on their study ‘Comparison of the configuration of the posterior bifurcation of the posterior communicating artery between fetal and adult brains: A study of a Sri Lankan population’ measured the external diameter of posterior communicating artery and P1 segment of posterior cerebral arteries in 34 fetal brain specimens and 225 adult cadaver brain. This study states that the blood supply to the occipital lobe by the posterior cerebral artery and the internal carotid artery was seen in 25(59%) and 16(34%) of fetal brain respectively. The transitional configuration of the posterior communicating artery is equal in diameter to P1 segment of posterior communicating artery is seen in 5(7.4%) with  $P < 0.0001$ .

**13. A.Krishnamoorthy et al 2008** in their study ‘Morphometry of posterior cerebral artery- embryological and clinical significance’ stated that out of 89 brain specimens with intact Circle of Willis the mean length and diameter of posterior cerebral artery were studied. The mean length of posterior cerebral artery was  $6.75\text{mm} \pm 1.482\text{mm}$  and mean diameter was  $1.7 \pm 0.7\text{mm}$ . The anomalous origin of posterior cerebral artery was reported in this study and it concludes that the presence of anomalous origin of posterior cerebral artery

assume significance in case of obstruction to the artery by an embolus.

**14. Prathapratim Pradhan 2009** on his study 'Morphological study of Circle of Willis' stated that variability of the anterior communicating artery were characterized by duplication, whereas the posterior communicating arteries showed morphological asymmetry. No aneurysm was found in any part of the arterial anastomosis or related arteries. Most anomalies were found on the left side(75%). However, variations were found almost equal in male(92.5%) and female (90%). The length of anterior communicating artery range from 2mm to 6mm, posterior communicating artery range from 11mm to 38mm and posterior cerebral artery range from 3mm to 11mm.

**15. Hina Siddiqi et al 2010** 'Variations in Cerebral Arterial Circle of Willis in Adult Pakistani population' out of 51 specimens, stated that 25 (49%) had asymmetrical arrangements, 39 (76.4%) had different types of variations in their component vessels. Posterior communicating artery showed more variation followed by anterior communicating artery in this study.

**16. Nordon et al 2012** on their study “Variations in the brain circulation- Circle of Willis’ studied fifty cadavers on the Brazilian population”. The results were, 54% showed at least one variation common in the posterior circulation (88.5%) on the right side of the brain (59.7%), non-classical morphology was more common bilaterally and in the posterior circulation of the Circle of Willis(37%). The most common finding was the absence of the posterior communicating artery (32%), followed by posterior cerebral arteries originated from the internal carotid artery (18%). Accessory anterior cerebral arteries were present in 6%. This study concluded that variations were seen in atleast 54% and no difference is seen between races in the variations of brain circulation.

**17. According to Mamatha et al 2012**, ‘Human cadaveric study of the morphology of the Basilar artery’, variation was found in one specimen showing the basilar artery terminates into two superior cerebellar arteries, the posterior cerebral artery arise from internal carotid artery and a communicating branch was present between the terminal part of the basilar artery and the posterior cerebral artery on the left side. In another specimen, unilateral variation was seen, with the posterior cerebral artery arising from the internal carotid

artery on the right and a posterior communicating artery arising from the posterior cerebral artery, connecting with the basilar artery.

**18. Anubha Saha et al 2013** on their article, 'Variation of Posterior Communicating Artery in Human Brain: A morphological study' stated that among 60 specimens collected from adult donated cadavers, 38.2% of cases showed absent posterior communicating artery and 23.3% cases were found to be hypoplastic. This study concludes that exact knowledge of the variation of posterior communicating artery is essential not only to explain various neurological symptoms but also for successful micro-vascular surgery in this region.

**19. S.Iqbal 2013** stated that the "majority of the circles showed anomalies. Among 50 randomly selected specimens, 52% were found to be anomalous. Hypoplasia was the most common anomaly reported and was found in 24% of the brain and posterior communicating artery was found to be more frequent. Accessory vessels (duplication/triplication) of anterior communicating artery were seen in 12% of the circles".

**20. Iman Sinha et al 2014** "Variation in the pattern of Circle of Willis in human brain- A morphological study and review' studied 80

specimens of human brain of both sexes, aged between 20-60years which were obtained from voluntary body donation. 62 out of 80 specimens (77.5%) have been found to be complete, symmetrical and having normal length and caliber. 7 specimens (6.25%) were incomplete and heptagonal in shape. This study states that most variations are seen in posterior communicating artery (10%) followed by anterior cerebral artery (6.25%) and anterior communicating artery (6.25%) and the most common type of variation is hypoplasia.

**21. H.R.Sharada et al 2014** ‘Morphometric Analysis and Variations of the Circle of Willis’ stated that out of fifty cadaveric brain specimens (35male and 15female), only 2 specimens showed variation and the rest showed normal pattern. The two variations include double anterior communicating artery and hypoplasia of posterior communicating artery.

**22. Sushma R.K et al 2014** on their case report stated that both the anterior cerebral artery were arising from the left internal carotid artery and the right anterior cerebral artery had a small communication from the right internal carotid artery. In addition, both posterior communicating arteries were large and continued as posterior cerebral arteries from the basilar artery. Such anomaly in

this network will lead to conditions like stroke by impairing the vital blood circulation.

23. According to **Nebojsa N Stojanovic 2015** on his study 'Characterization of the variations of Circle of Willis in the series of subject autopsy', 56 subjects were studied, changes in anterior segment were found in 42.8%. Out of that, forty one percent were found in anterior communicating artery. In 16%, the A1 segment affected the symmetry of Circle of Willis. 10.9% of the fetal type of posterior communicating artery and 30.4% with the hypoplasia of anterior communicating artery.

24. **Vaibhav V. Sande 2016** 'Variations of the anterior part of Circle of Willis in human cadavers' a dissection study stated that variations of the anterior part of Circle of Willis are not quite rare. The most common variation seen was the absence anterior communicating artery. Among 30 specimens, 5 cases were reported to have anomalous. The anterior cerebral artery was absent in 2 cases and hypoplastic artery in one case.

25. According to **Prasanna Veera Kumar 2016** on his article 'A study of Variation of Circle of Willis in the Adult Population of South India' stated that out of 50 embalmed cadaver brain studied, 60% of

brains showed complete Circle of Willis. The most common anomaly is the abnormal diameter of the arteries and is found to be more frequent in the posterior communicating artery. The second most common anomaly is the absence of the component vessels, the posterior communicating artery is again frequent. Another additional changes reported in this study were (i) the right posterior cerebral artery is thin and was dividing into slender branches after some distance (ii) one of its branches was joining the hyperplastic anterior choroidal artery and (iii) the posterior communicating artery was absent on both sides.

- 26. Narayana Rao** reported hypoplastic posterior cerebral artery on the right side and stated that there is increased risk of posterior circulation stroke and knowledge of awareness of the normal variant should be taken into consideration during investigation and interventional procedures.



## **RADIOLOGICAL STUDY:**

27. **Kalula N.T.Kayembe 1984**, “Cerebral Aneurysms and Variations in the Circle of Willis” studied about the variation of the Circle of Willis and aneurysms. The most numerous aneurysms were seen in anterior communicating artery (40.3%) followed by middle cerebral artery with 22.4%. There were slightly more aneurysms on the right side of the circle than the left. This study concludes that variations in the Circle of Willis play some role in the development of cerebral aneurysms.
28. **Miralles et al 1995** on their study “The role of the Circle of Willis in carotid occlusion: assessment with phase contrast Magnetic Resonance Angiography and transcranial duplex” with 38 patients with internal carotid artery occlusion in symptomatic patients. The data suggested in the study is that collateral blood supply is enough to maintain normal hemispheric perfusion. The anterior communicating artery plays an key collateral pathway as non-functioning anterior communicating artery is associated with an increased risk of developing low flow infarcts.
29. **Stock K.W 1996** on their study Anatomic evaluation of the Circle of Willis stated that Magnetic Resonance Angiography is a

sensitive technique for detecting the anatomy of the Circle of Willis. Maximum intensity projection images are more specific than source images and arterial segment with the diameter of atleast 1mm on the source images are almost always present and patent.

30. **M J Krabbe-Hartkamp et al 1998** took one hundred and fifty samples of Magnetic Resonance Angiography and concluded that 111 (74%) subjects demonstrated a complete anterior part of the circle, 78 (52%) demonstrated a complete posterior part of the circle, and 63 (42%) demonstrated an entirely complete Circle of Willis (complete anterior and posterior parts of the circle combined). The presence of an entirely complete Circle of Willis was slightly higher in younger persons and in women. Most vessel diameters were smaller in women, except for the diameter of the posterior communicating artery.
31. **A.W.J.Hoksbergen 2000** stated that collateral pathway is essential for maintaining the cerebral blood flow. Failure of this pathway was caused by hypofunctional communicating arteries.
32. **Hsin Wen Chen et al 2004**, “Magnetic Resonance Angiographic Evaluation of Circle of Willis in General Population: A

Morphologic Study in 507 Cases” stated that the configuration of Circle of Willis may vary largely in general population. The prevalence of complete configuration of the circle is higher in younger persons as well as in female. This normal anatomical difference may be correlated to the development of cerebrovascular disease.

**33. Jeroen Hendriskse et al 2005** on their study “Distribution of cerebral blood flow in the Circle of Willis” measured the volume blood flow in the basilar artery and the internal carotid artery among 208 patients with atherosclerosis or risk factor for atherosclerosis. The internal carotid artery volume flow in subjects with a complete configuration of the Circle of Willis was 245ml/min $\pm$ 65 (standard deviation). The flow is considerably increased when there is a missing A1 segment. In the subjects with a unilateral or bilateral fetal type posterior cerebral artery, the internal carotid artery volume flow was increased and the basilar artery flow was decreased in comparison with the flow in subjects with no fetal-type Circle of Willis.

**34. H.Tanaka et al 2006** studied variations in the pattern of Circle of Willis among 117 subjects and stated that 105 showed normal pattern, six each showed A1 hypoplasia and P1 hypoplasia. This

study also measured the total flow rates for the three variations. This study concludes that the variation in the Circle of Willis correlate significantly with relative contributions by the flow rates of the bilateral internal carotid and basilar arteries.

**35. Yu Ming Chang 2007** on their study, “Anterior Cerebral Artery A1 Segment Hypoplasia may contribute to A1 Hypoplasia Syndrome”- studied 280 patients with Magnetic Resonance Angiogram with aged 60-80years admitted with history of acute ischemic stroke. This study stated that anterior cerebral artery A1 segment hypoplasia is an uncommon fetal variant of the Circle of Willis. The frequency of this variation is 1-13% as derived from angiograms and autopsy reports. Impaired collateral blood flow through the Circle of Willis is a recognized risk factor for ischemic stroke. The A1 segment of the anterior cerebral artery is the principle supplier of anterior collateral blood flow and A1 hypoplasia may be responsible for acute ischemic stroke.

**36. Kawther A. Hafez 2007**, “Anatomical Variations of the Circle of Willis in Males and Females on 3D Magnetic Resonance Angiograms” took 120 specimens unrelated to any ischemic or vascular diseases and they were considered as healthy control. The anatomical variations of the anterior part, posterior part and

completeness of the circle were inspected. The study postulated that, the anterior part of the circle was complete in 70% of males and 75% of females and there is no significant difference between the sexes. The posterior part of the circle was complete in 48% males and 58% of females. The most common variant was the bilateral posterior communicating arteries, followed by unilateral posterior communicating artery. An entire complete circle was found only in 45% of the entire population and it was higher in the females than in the males. In addition, 10 cadaveric brain was dissected and among that, six cases showed normal circle , three cases showed unilateral fetal posterior communicating artery and one case showed absent posterior communicating artery.

- 37. Haripriya 2010** on their study “A Study of the Anatomical Variations of the Circle of Willis Using Magnetic Resonance Imaging” in fifty patients of South Indian population. All arteries showed variations except anterior communicating artery, five cases showed variations in the anterior cerebral artery, six cases in the internal carotid artery, two cases in the posterior cerebral artery, one case in the posterior communicating artery and two cases in the basilar artery. This study concluded that Magnetic Resonance

Imaging is the best tool to show the collateral circulation and the anastomotic variants of the Circle of Willis.

38. **Mohamed Abdelaziz Maaly 2011** studied 250 patients and stated that complete anterior and posterior part of Circle of Willis were seen in 68.3% and 38.3% respectively. Complete classical circle were seen in 46.7%. The prevalence of entirely complete Circle of Willis was slightly higher in females and young than males and older subjects. This study concludes that statistically significant difference is found in vessel diameter in relation to age and sex.
39. **R.Shane Tubbs 2013** on his review described the Circle of Willis as an important communication between the blood supply of the forebrain and the hindbrain. A complete Circle of Willis is present in most individuals, although a well developed communication between each of its parts identified is less than half of the population. Asymmetry of the Circle of Willis results in significant asymmetry of flow and is an important factor in the development of intracranial aneurysms and ischemic stroke. Uncommonly, persistence of fetal anastomosis involving Circle of Willis such as persistent trigeminal, otic, hypoglossal and proatlantal arteries are rarely seen. These arteries more or less unite the internal carotid and vertebrobasilar system.

40. **Alma Volijevica et al 2013** ‘Morphometric analysis of Willis circle arteries’ stated that the arterial circle is the most important part of the collateral circulation to the brain. 100 angiograms of carotid system were studied. It was observed that larger diameters of blood vessel in Circle of Willis were observed in the younger subjects compared to older except the diameter of the internal carotid artery which was 0.2 to 0.3mm larger in the older subjects.
41. **Bishwajeetsaikia et al 2014** on their study with both gross dissection and with Magnetic Resonance Angiography, took 140 specimens and concluded that only 22.14% present with a complete Circle of Willis, out of which 20% were cadaveric specimen and 24% were in Magnetic Resonance Angiogram group.
42. **ChuanyaQiu et al 2014**, ‘Magnetic Resonance Angiogram study on variation of the Circle of Willis in healthy Chinese male adults studied 2,246 healthy subjects using typical MAGNETIC RESONANCE ANGIOGRAM. The results were 1.The overall incidence of Circle of Willis 12.24%, with 7.57% non variation integrity. 2. The incidence of partial integrity and non integrity were 70.17% and 17.59% respectively. The integrity rate of anterior circulation was 78.58% with a close correlation with A1

segment of the anterior cerebral artery. This study concludes that Circle of Willis variation is a common phenomenon among the healthy subjects and MAGNETIC RESONANCE ANGIOGRAM could enable reflecting the physiological morphology of Circle of Willis in a comprehensive manner.

43. **Ace Dodevki et al 2014** studied about the diameter of posterior cerebral artery and compared on both sides. The posterior cerebral artery was  $1.74 \pm 0.3\text{mm}$  on the right side and  $1.98 \pm 0.4\text{mm}$  on the left side. The adult configuration was present in 37 specimens and fetal type was seen in 12 and transitional configuration was present in 4 of the patients. This study concluded that the frequency of fetal posterior cerebral artery was present in 22.64%.
44. **Guangyu Zhu et al 2015** on their study of hemodynamics in the circle of circulation stated that the Circle of Willis is an important collateral pathway of the cerebral blood flow. Their study concluded that posterior communicating artery is the most important collateral pathway of the collateral circulation and the missing of the posterior communicating artery has the highest risk of stroke when the ipsilateral internal carotid artery has severe stenosis.



45. **Ayşe Karatas et al 2015** on their study with one hundred adult specimen who underwent Computerized Tomography images among Turkish population. Results of the study revealed 82% adult type, 17% fetal type and 1% transitional configurations. A complete polygonal structure was observed in 28% of cases and variations of the Circle of Willis were more common in the posterior portion. Hypoplasia was found to be the most common variation and was observed as a maximum in the posterior communicating artery.
46. **Shankar Rao Naveen 2015**, 'Magnetic Resonance Angiographic evaluation of Circle of Willis stated that out of 300 patients taken into study, complete circle was seen in 50 subjects(16.6%) slightly higher in females and younger subjects. Complete anterior circle was present in 77.3%. Most common anterior variant is type A with a prevalence of 66% and among posterior circle is type E. Overall, variants are slightly more common among the women in comparison to men.
47. **Arjun Bahaddur 2016** stated that the prevalence of complete configuration of the circle is 16.6%. The most common posterior circle variant is hypoplasia of the posterior communicating artery with 32.6% and variation are slightly more common among the women in comparison to men.

# **MATERIALS AND METHODS**

## **MATERIALS OF STUDY:**

1. 50 embalmed adult human brain specimens were obtained and studied.
2. 50 Magnetic Resonance Angiography images were obtained and studied.

## **METHOD OF STUDY:**

A. DISSECTION METHOD.

B. RADIOLOGICAL METHOD.

## **DISSECTION METHOD:**

This study was done in the Department of Anatomy, Stanley Medical College on 50 preserved human cadavers irrespective of their sex and age. The brain specimens were dissected and studied between the years 2015-2017. The guidelines of Cunningham's manual of practical Anatomy were followed(fig5).

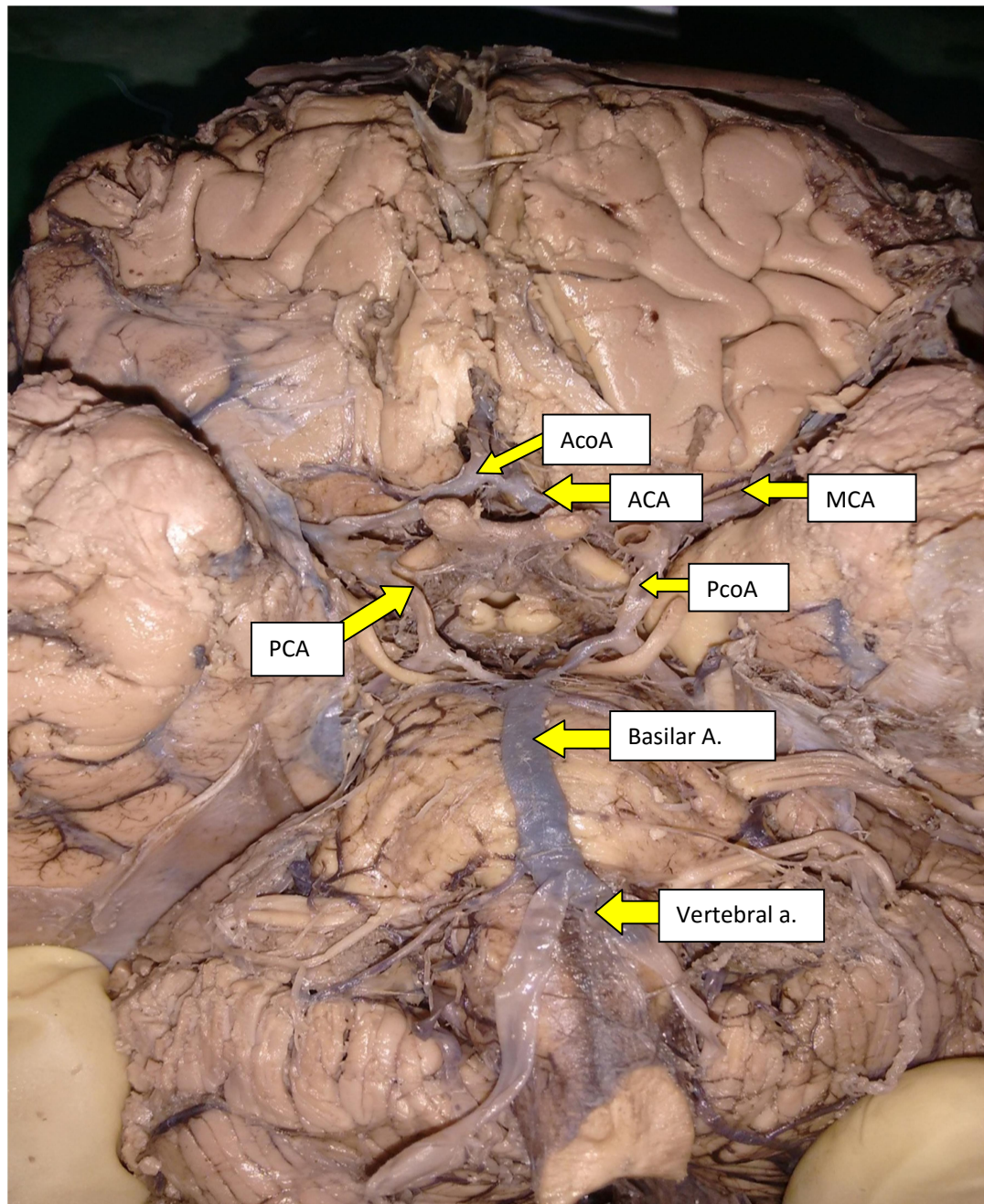


Fig 5: Cadaveric specimen showing the Circle of Willis. AcoA- Anterior communicating artery. ACA-Anterior cerebral artery. MCA- Middle cerebral artery. PcoA- Posterior communicating artery. PCA- Posterior cerebral artery.

The skull cap was removed after making a pencil mark on the skull not more than one cm above the orbital margins and the external occipital protuberance. Using chisel and hammer, vault of the skull was opened along the marked line and the skull cap is removed. The meninges are reflected and the brain is removed carefully by cutting the cranial nerves near their exit along the various foramina and spinal cord is detached from it below the level of medulla oblongata. The vertebral arteries, basilar artery and internal carotid arteries are traced. Then the Circle of Willis is exposed by opening the interpeduncular cisterns at the base of the brain (**Cunninghams manual 15<sup>th</sup> edit**). The base of the brain including the brainstem with intact arterial circle was preserved in 10% formalin for 10 days. The Circle of Willis and its major branches were carefully dissected. The photos of Circle of Willis and their variations were taken and documented.

The Circle of Willis is present in the interpeduncular cistern at the base of the brain (**Gray's Anatomy 40<sup>th</sup> Edit.**). The Circle of Willis is a major collateral blood flow and principal anastomotic trunk to the brain connecting the vertebrobasilar and the internal carotid arteries.

A caliper graduated to measure up to 0.02mm was used to measure the diameter of the vessels. The arteries less than 1mm in diameter for

cerebral vessels and less than 0.5mm for communicating arteries were considered as hypoplastic (**Prasanna Veera Kumar 2016, S.Iqbal 2013**)

### **RADIOLOGICAL METHOD:**

The radiological study was conducted in the Department of Radiology, Stanley Medical College and Hospital from 2015-2017. The patients coming to the hospital as out patient as part of their health checkup were included in the study.

A total of 50 Magnetic Resonance Angiogram images were taken for the study with the proper informed consent from each individual. Clearance from the Institutional Ethical Committee was obtained before the start of study.

The technique used was three Dimensional Time of Flight Magnetic Resonance Angiography (3D-TOF-MRA) using 1.5Tesla MRI scanner. Only the arteries forming the Circle of Willis were taken into study. Following imaging parameters were used repetition time/echo time 23/7.0, flip angle 25 degrees, slice thickness 0.7mm, number of slice 44/slab, number of slabs 4, slice overlap 25%, flow direction feet to head with 40mm saturation at the head end, field of view 180x158 and 256 matrix size (**Bishwajeetsaikia et al 2014**). For the purpose of

identification, the Circle of Willis is divided into anterior and posterior configuration (fig 6).

The following parameters of Circle of Willis were noted in this study from both Dissection and Radiological methods.

1. Complete or incomplete formation.
2. Shape of the Circle of Willis.
3. Normal or abnormal caliber.
4. Symmetrical or asymmetrical pattern.
5. Morphological variations like absent vessels, attenuation, duplication / triplication and abnormal origin were studied.

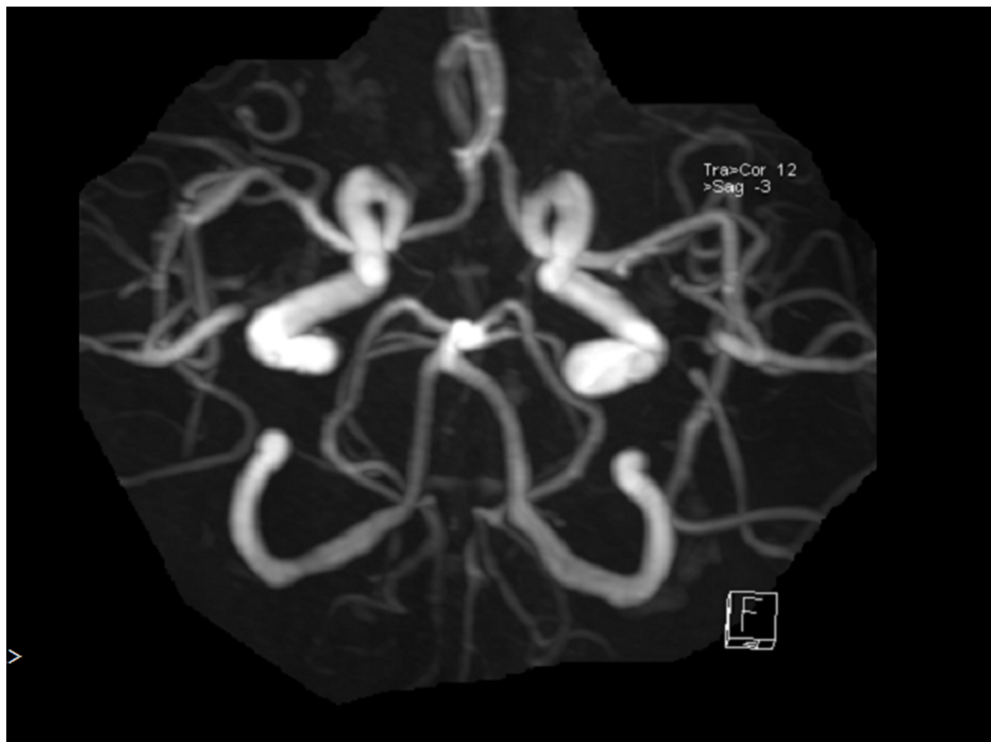


Fig 6: Magnetic resonance Angiography showing Circle of Willis.

# OBSERVATION

## MORPHOLOGICAL STUDY:

The internal carotid artery bifurcates at the medial end of the lateral sulcus into anterior and middle cerebral arteries. The middle cerebral artery runs in the sylvian fissure while the anterior cerebral artery runs in the longitudinal fissure and are connected by the anterior communicating artery (**Vaibhav V et al 2016**). The basilar artery which is formed by the union of two vertebral arteries at the pontomedullary junction and bifurcates into two posterior cerebral arteries (**Ranganathan T S 3<sup>rd</sup> edit**). The anterior circulation and the posterior circulation are connected by the posterior communicating artery.

The anterior cerebral artery from the origin to the level until the junction of anterior communicating artery is considered circular part of A1 segment. The posterior cerebral artery from its origin from basilar artery until the level of junction of posterior communicating artery is considered circular part of P1 segment (**Iman Singh 2014**).

The normal circle is complete, polygonal in shape and symmetrical in configuration. The cerebral arteries and communicating artery are considered hypoplastic if the diameter is less than 1mm and 0.5mm

respectively (**Gray's Anatomy, S.Iqbal,BishwajeetSaikia**). Among the 50 brain specimens, the morphology is considered under four parameters.

1. Complete form.
2. Symmetrical.
3. Normal caliber.
4. Polygonal in shape.

Out of 50 specimens, 29 specimens(58%) were found to have complete normal symmetrical configuration, normal caliber and polygonal shape. Other 21(42%) specimens were abnormal either incomplete or asymmetrical or hypoplastic. Abnormalities in the vertebral and basilar artery were not taken into consideration in this study.

#### **Anomalous circle:**

The present study shows 21(42%) anomalous circle and are described below.

#### **I. INCIDENCE OF ABSENCE VESSELS:**

The least common anomaly seen in the variation of the Circle of Willis is the absence of either the cerebral or the communicating arteries. The posterior communicating artery was found to be absent in one



specimen. The absence of anterior communicating artery was not encountered in the study (Table 1).

<b>Name of the vessel</b>	<b>No. of absent vessel</b>	<b>Percentage</b>
<b>Anterior cerebral artery(A1)</b>	-	-
<b>Anterior communicating artery</b>	-	-
<b>Posterior cerebral artery(P1)</b>	-	-
<b>Posterior communicating artery</b>	<b>1</b>	<b>4.7</b>

Table 1: showing number and percentage of absent vessels out of 21 specimens.

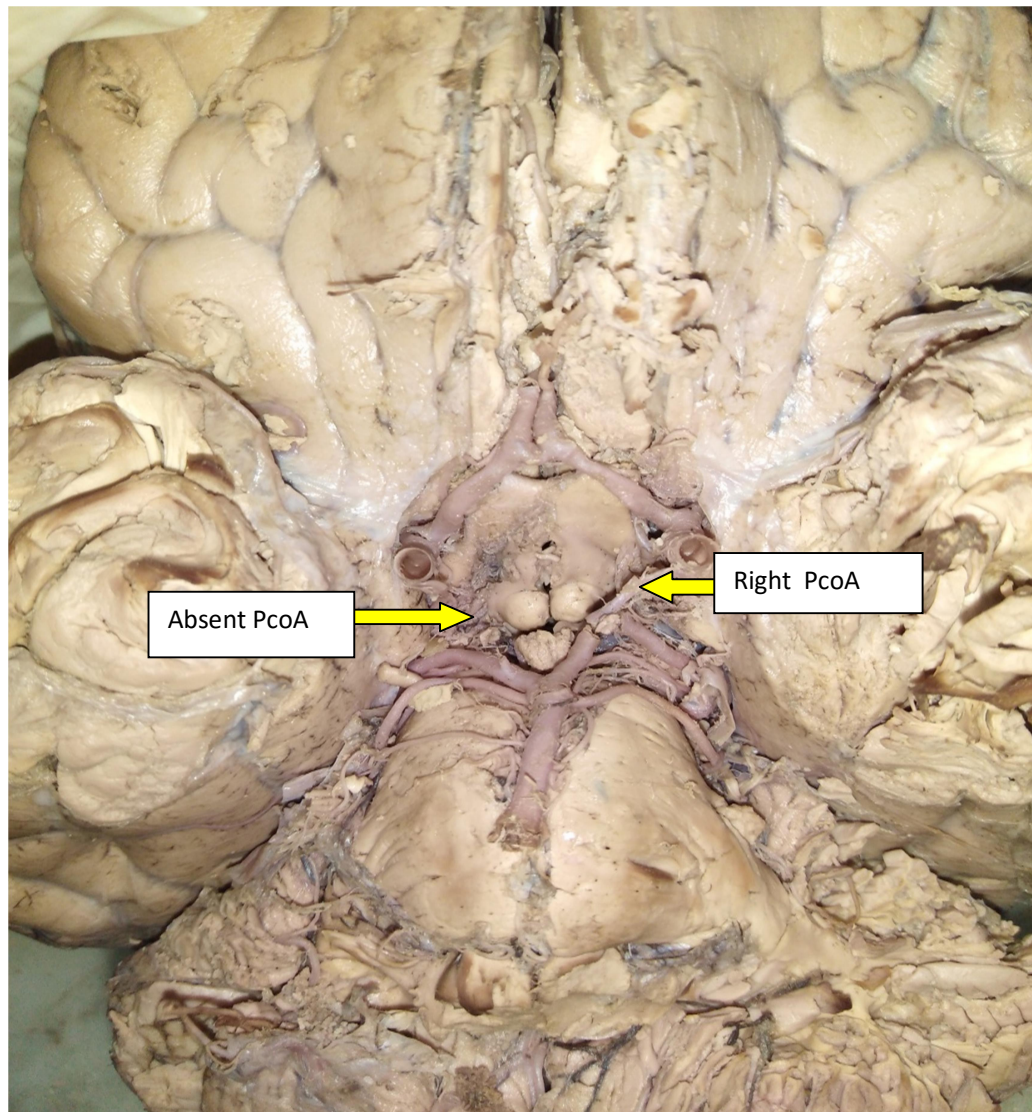


Fig 7: Absent posterior communicating artery.

## II. INCIDENCE OF HYPOPLASTIC VESSELS:

Cerebral arteries of less than 1mm in external diameter while less than 0.5mm in diameter for communicating artery were considered hypoplastic (**Gray's Anatomy, S.Iqbal, Bishwajeet Saikia**). The common anomaly encountered is the hypoplasia of one or

other components of the Circle of Willis. Posterior communicating artery were found to be more frequent among hypoplastic vessels followed by posterior cerebral artery. The incidence of hypoplasia is depicted in Table 2.

<b>Name of the vessel</b>	<b>No. of hypoplastic vessel</b>	<b>Percentage</b>
<b>Anterior cerebral artery (A1)</b>	<b>1</b>	<b>4.7</b>
<b>Anterior communicating artery</b>	<b>1</b>	<b>4.7</b>
<b>Posterior cerebral artery(P1)</b>	<b>3</b>	<b>14.28</b>
<b>Posterior communicating artery</b>	<b>8</b>	<b>38.09</b>

Table 2: depicting the incidence of hypoplasia among cerebral and communicating vessels out of 21 specimens.

The posterior communicating artery shows high percentage of hypoplasia (38.09%) among all the vessels taken for the study(fig 8).

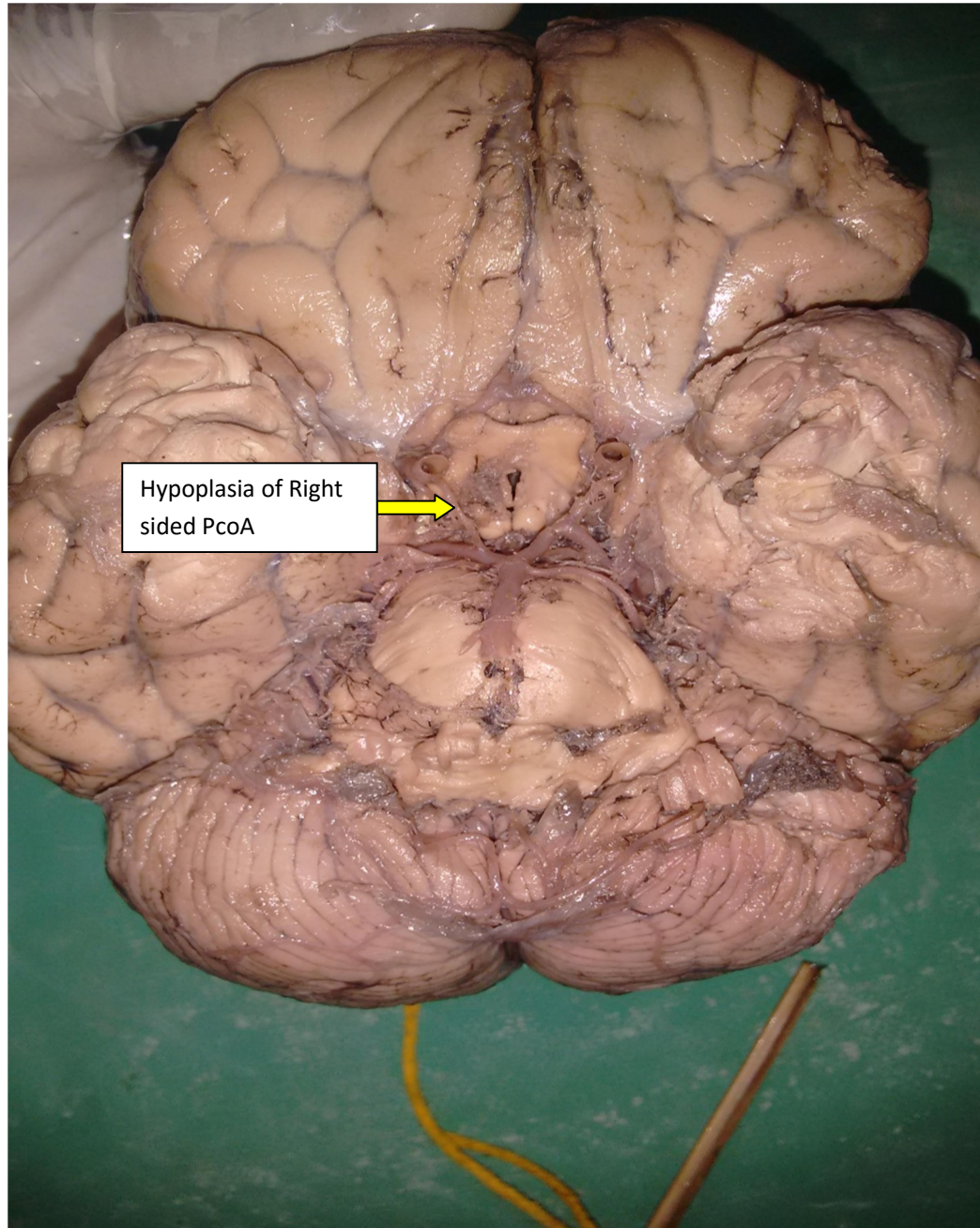


Fig 8: Showing hypoplasia of Posterior communicating artery.

### III. INCIDENCE OF ACCESSORY VESSELS:

The accessory vessels were present in the form of duplication or triplication of one of the component of Circle of Willis. Duplication of component vessels were seen while triplicate vessels were not found in any specimens. Out of 21 variations seen, 5 specimens showed accessory vessels in the form of duplication(fig 9,10). The anterior communicating artery were found to be more among all the vessels(19.04%). No duplication or triplication were seen in posterior part of Circle of Willis (Table 3)

<b>Name of the vessel</b>	<b>No. of accessory vessel</b>	<b>Percentage</b>
<b>Anterior cerebral artery (A1)</b>	<b>1</b>	<b>4.7</b>
<b>Anterior communicating artery</b>	<b>4</b>	<b>19.04</b>
<b>Posterior cerebral artery(P1)</b>	<b>-</b>	<b>-</b>
<b>Posterior communicating artery</b>	<b>-</b>	<b>-</b>

Table 3 showing incidence of accessory vessels and percentage out of 21 specimens.



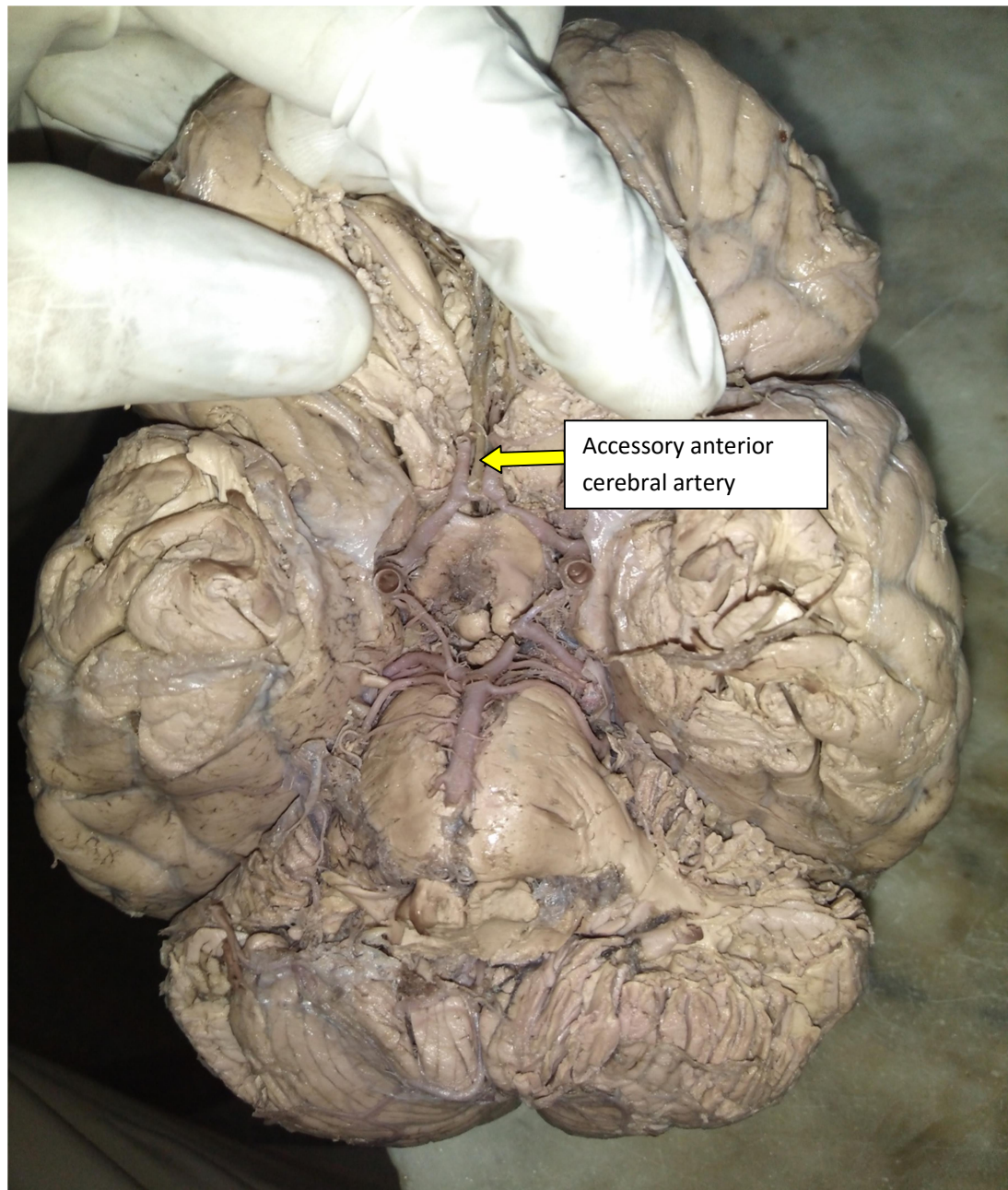


Fig 9: Accessory Anterior cerebral artery

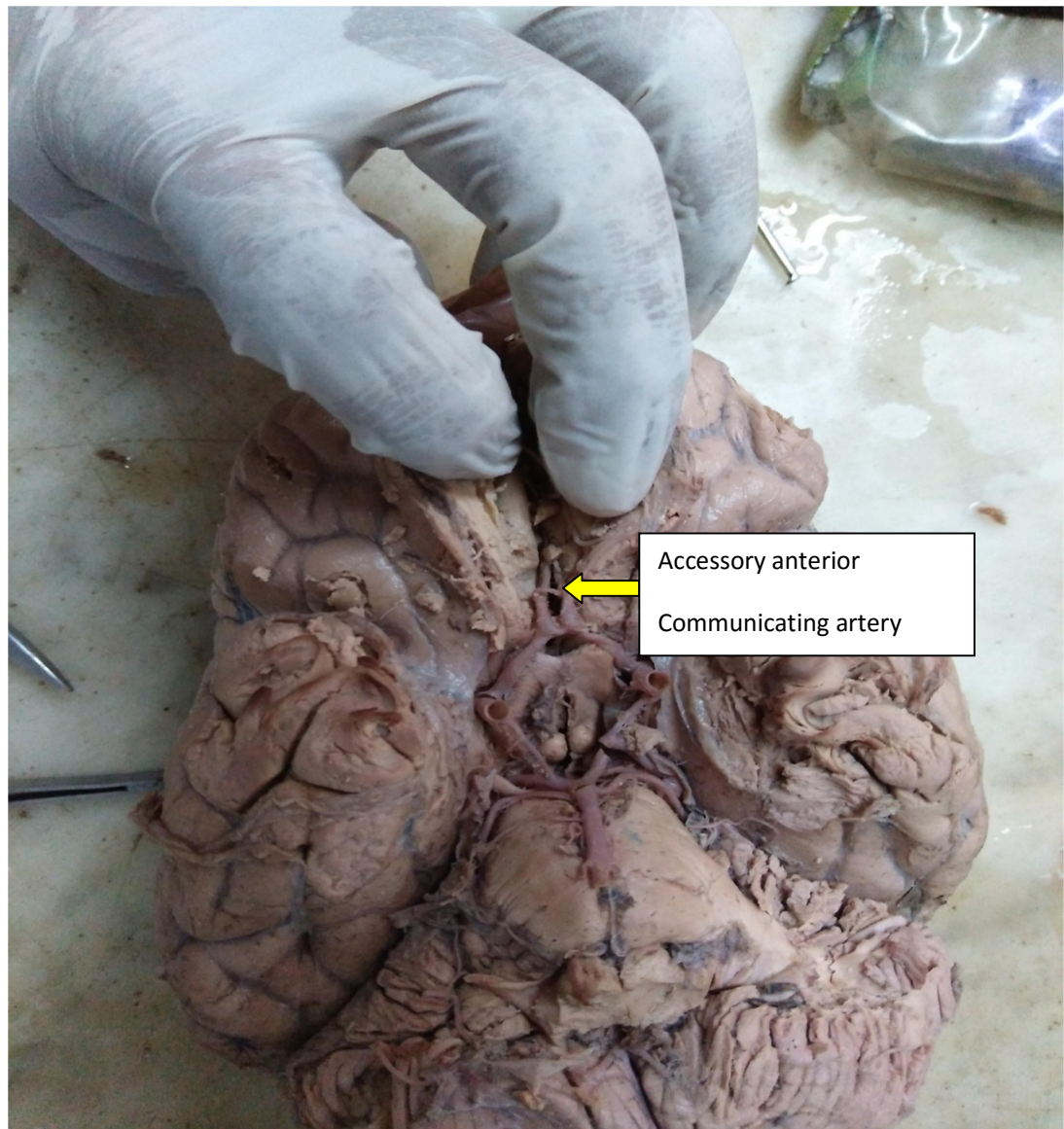


Fig 10:Accessory Anterior communicating artery.

#### IV. INCIDENCE OF ANOMALOUS ORIGIN:

The fetal origin of posterior cerebral artery from the internal carotid artery is common variant in the posterior part of the circle. Here the posterior cerebral artery is small, hypoplastic or even absent and in order to compensate for the posterior circulation, the posterior cerebral artery is connected by a small communicating type of vessel. In this study, fetal origin of Posterior cerebral artery was found in 2 specimens(9.52%). (Fig 11)

<b>Name of the vessel</b>	<b>No. of abnormal origin</b>	<b>Percentage</b>
<b>Anterior cerebral artery (A1)</b>	-	-
<b>Anterior communicating artery</b>	-	-
<b>Posterior cerebral artery(P1)</b>	<b>2</b>	<b>9.52</b>
<b>Posterior communicating artery</b>	-	-

Table 4: showing number of abnormal origin out of 21 specimens.

The other vessels show no abnormality(Table 4)



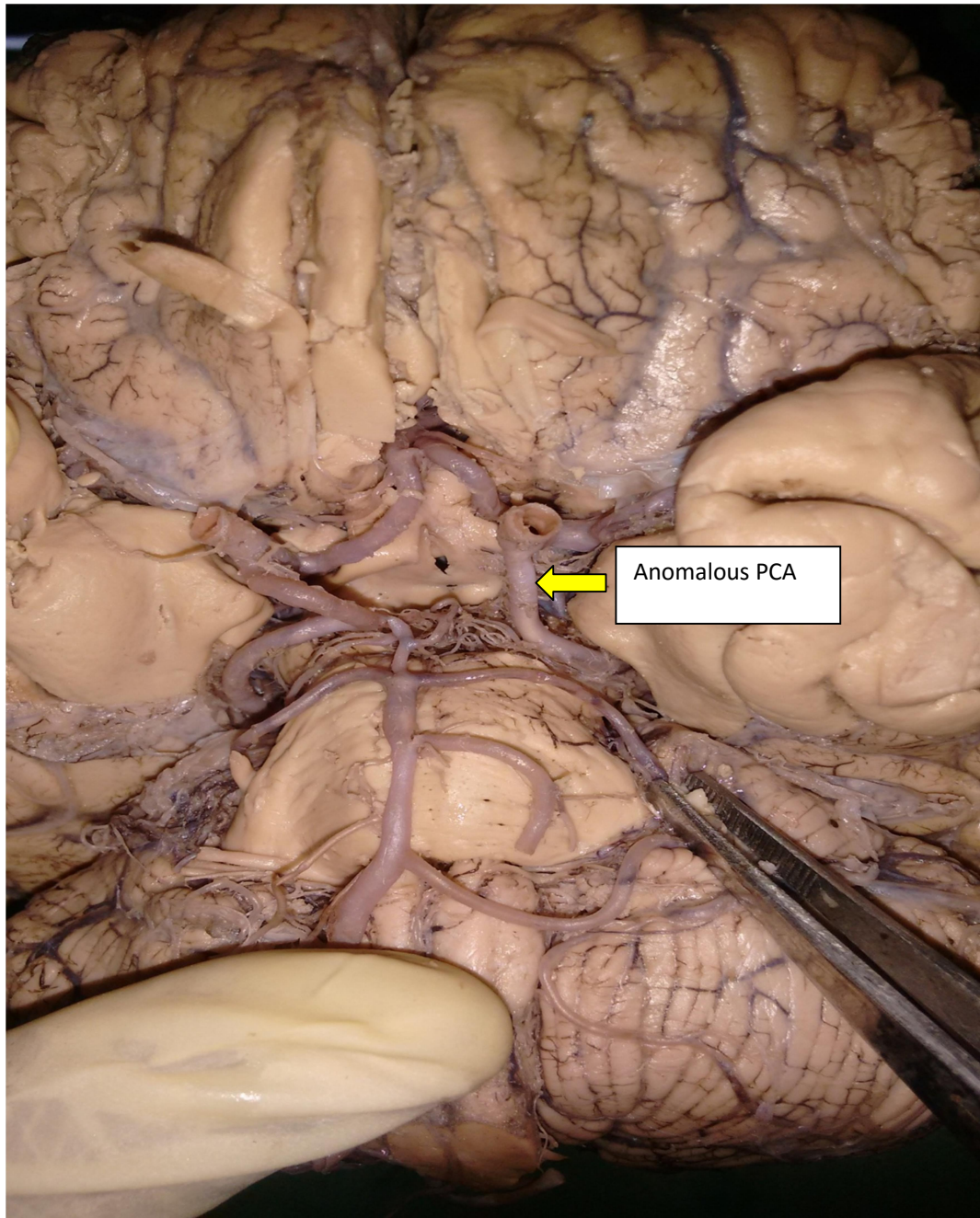


Fig 11: Anomalous origin of Posterior cerebral artery

**V. INCIDENCE OF VARIATION IN ANTERIOR AND POSTERIOR PART OF THE CIRCLE:**

<b>No./Percentage</b>	<b>Anterior circle</b>	<b>Posterior circle</b>
Number	7	14
Percentage	33.33	66.67

Table 5: showing percentage of variation in anterior and posterior part of circle.

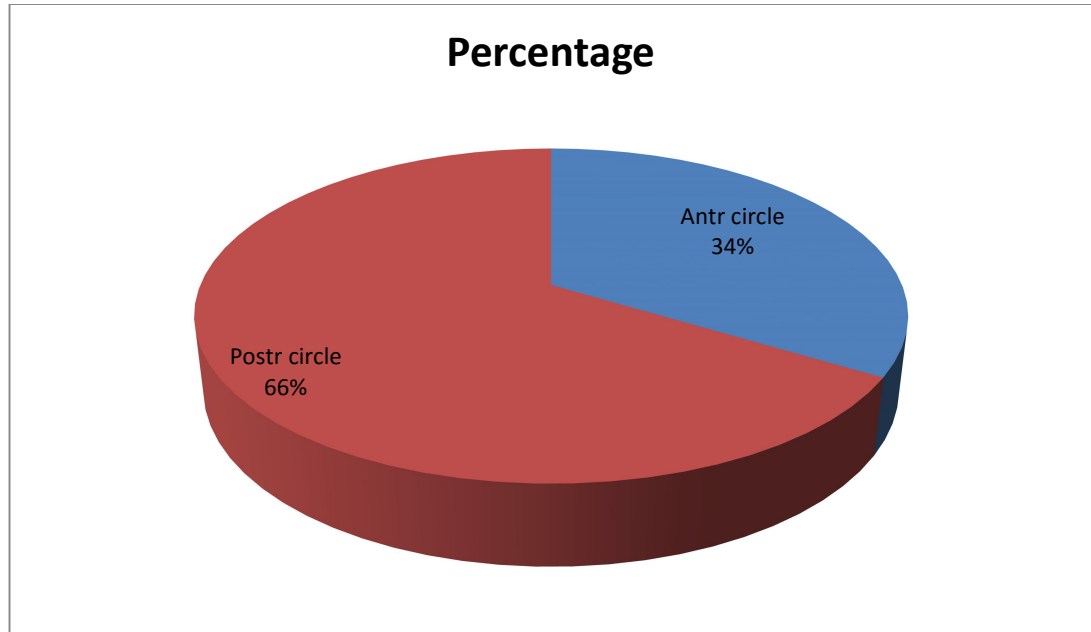


Fig 12: Pie chart showing graphical representation of incidence of variations of anterior and posterior circle.

## VI. VARIATION IN INDIVIDUAL VESSELS:

Name of the vessels	Absent vessels	Hypoplasia	Accessory vessels	Anomalous origin	Percentage (%)
Anterior cerebral artery	-	1	1	-	9.52
Anterior communicating Artery	-	1	4	-	23.80
Posterior cerebral artery	-	3	-	2	23.80
Posterior communicating Artery	1	8	-	-	42.86

Table 6: showing overall incidence of variation of individual vessels.

The overall variation of the anterior part of the circle is 33.33% while the posterior part of the circle is 66.67%. Among all the variations, hypoplasia of the posterior communicating artery were found to be common followed by hypoplasia of the posterior cerebral artery (fig 13)

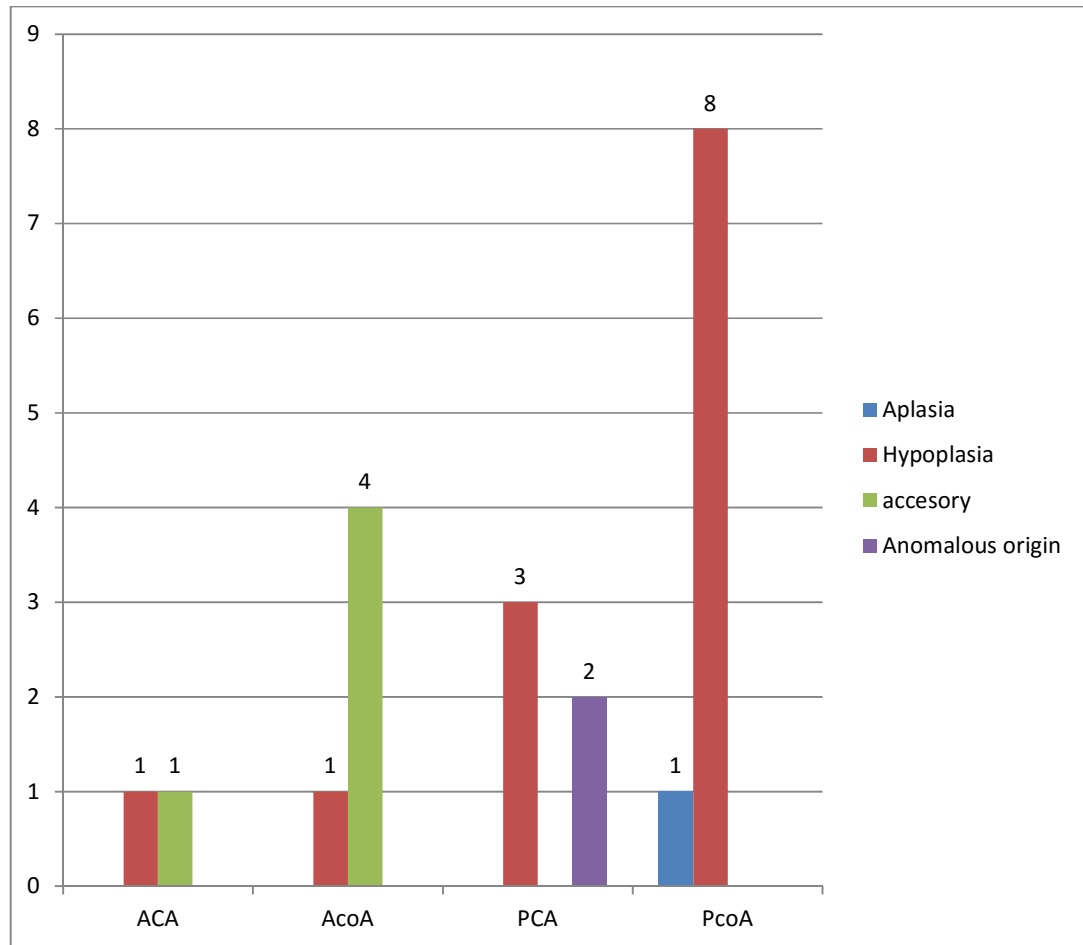


Fig 13: Coloumn showing graphical representation of variations of individual vessels.

<b>Name of the variations</b>	<b>Percentage of total variations</b>
Absent vessels	4.7
Hypoplasia	61.90
Accesory vessels	23.80
Anomalous origin	9.52

Table 7: showing percentage of total variations out of 21 specimens.

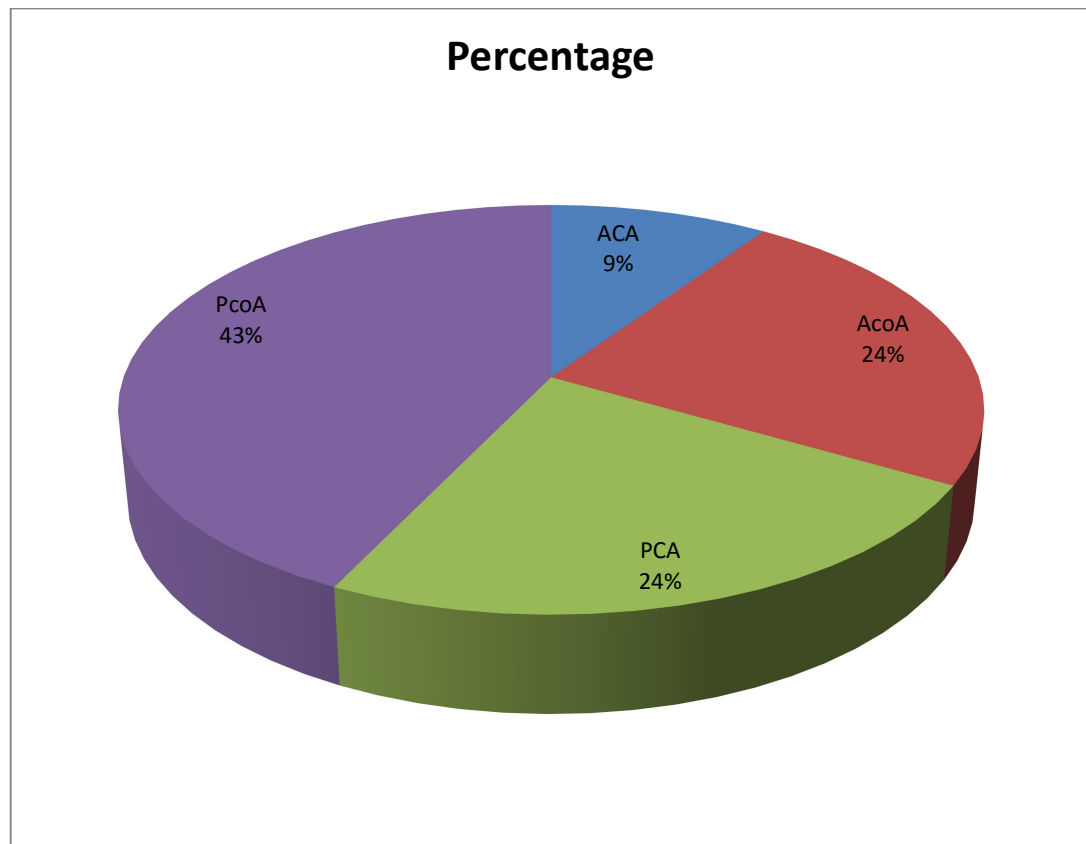


Fig 14: Piechart showing percentage of total variations.

<b>Name of the variations</b>	<b>Percentage for total specimens(50)</b>
Absent vessels	2
Hypoplasia	26
Accessory vessels	10
Anomalous origin	4

Table 8 : showing percentage among total specimens.

The most common variation noted is the hypoplasia of the cerebral and communicating vessels with a percentage of 61.90%. The next common variation is presence of accessory vessels with 23.80%. Among all the four vessels, Posterior communicating artery were found to have more variations (42.85%). Hypoplasia of posterior communicating artery with vessel diameter less than 0.5mm is 38.09%. followed by posterior cerebral artery with 14.2%.(Table 8).



## RADIOLOGICAL STUDY

Out of 50 cases, 34 cases were found to have normal, symmetrical and complete form of circle. The remaining 16 cases were found to be abnormal and showing one or more variations in the morphological patterns.

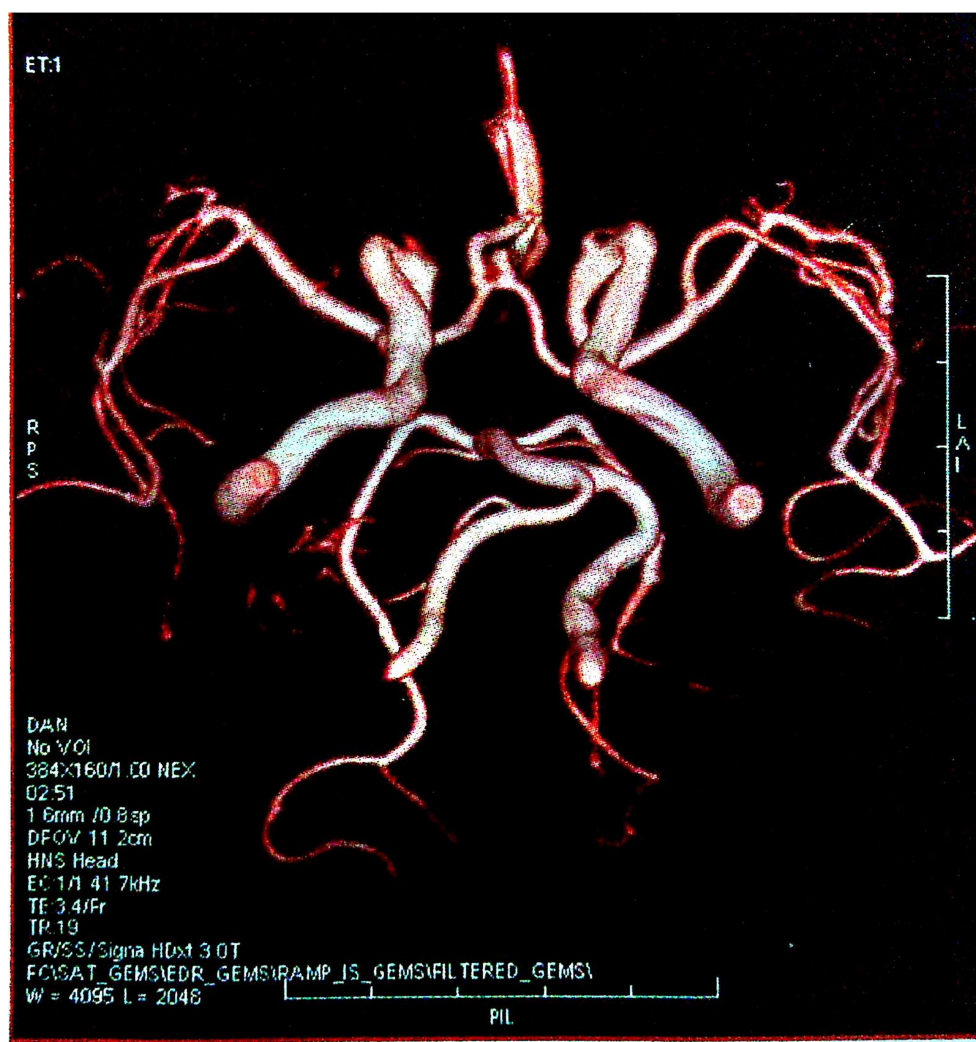


Fig 15: Showing normal Circle of Willis

### **ANOMALOUS CIRCLE:**

The sixteen specimen with anomalous circle were taken into consideration.

### **I.INCIDENT OF ABSENT VESSELS:**

In the present study, no case of absent vessels were reported in any of the vessel.

### **II.INCIDENT OF HYPOPLASTIC VESSELS:**

<b>Name of the vessel</b>	<b>No. of hypoplastic vessel</b>	<b>Percentage (%)</b>
Anterior cerebral artery (A1)	7	43.75
Anterior communicating artery	-	-
Posterior cerebral artery(P1)	4	25
Posterior communicating artery	1	6.25

Table 9: showing incidence of hypoplasia out of 16 specimens.

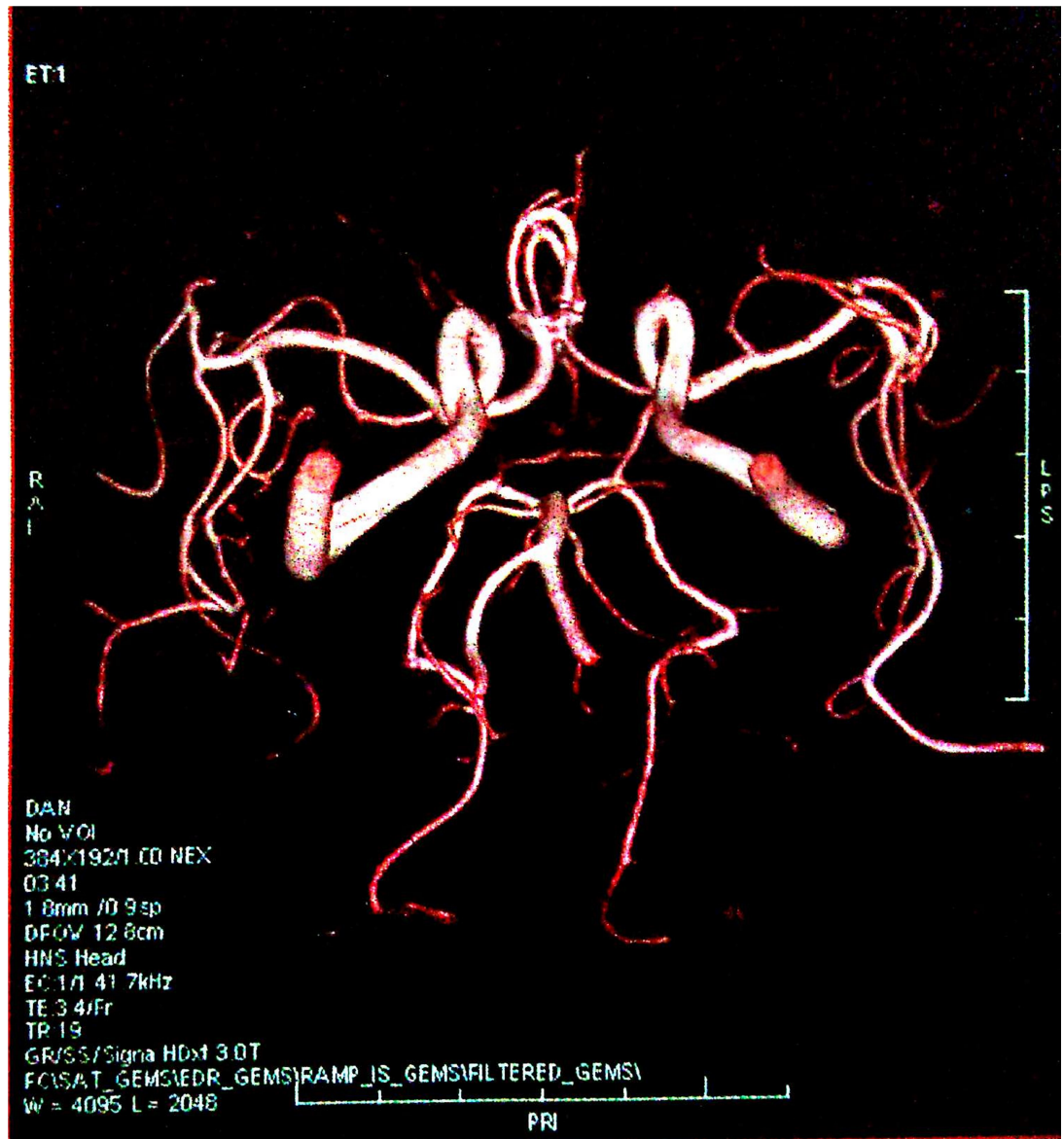


Fig 16. :Hypoplasia of left anterior cerebral artery.





Fig 17: Hypoplasia of right anterior cerebral artery.

The hypoplasia was found to be common in anterior cerebral artery in 7 cases with a percentage of 43.75%(fig 16, 17). The posterior cerebral artery was hypoplastic in 4 cases with a percentage of 25% and posterior communicating artery with one case with a percentage of 6.25%. The anterior communicating artery does not show any hypoplastic changes in this study.

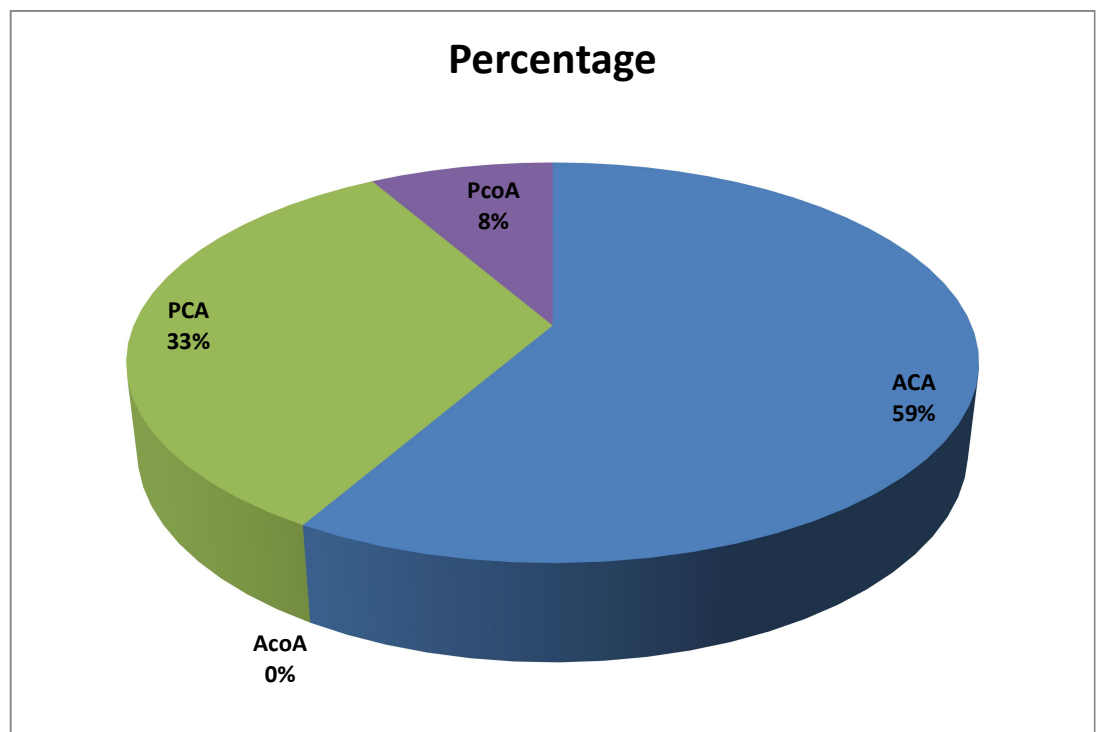


Fig 18: Piechart showing incidence of hypoplastic vessels in MAGNETIC RESONANCE ANGIOGRAM.



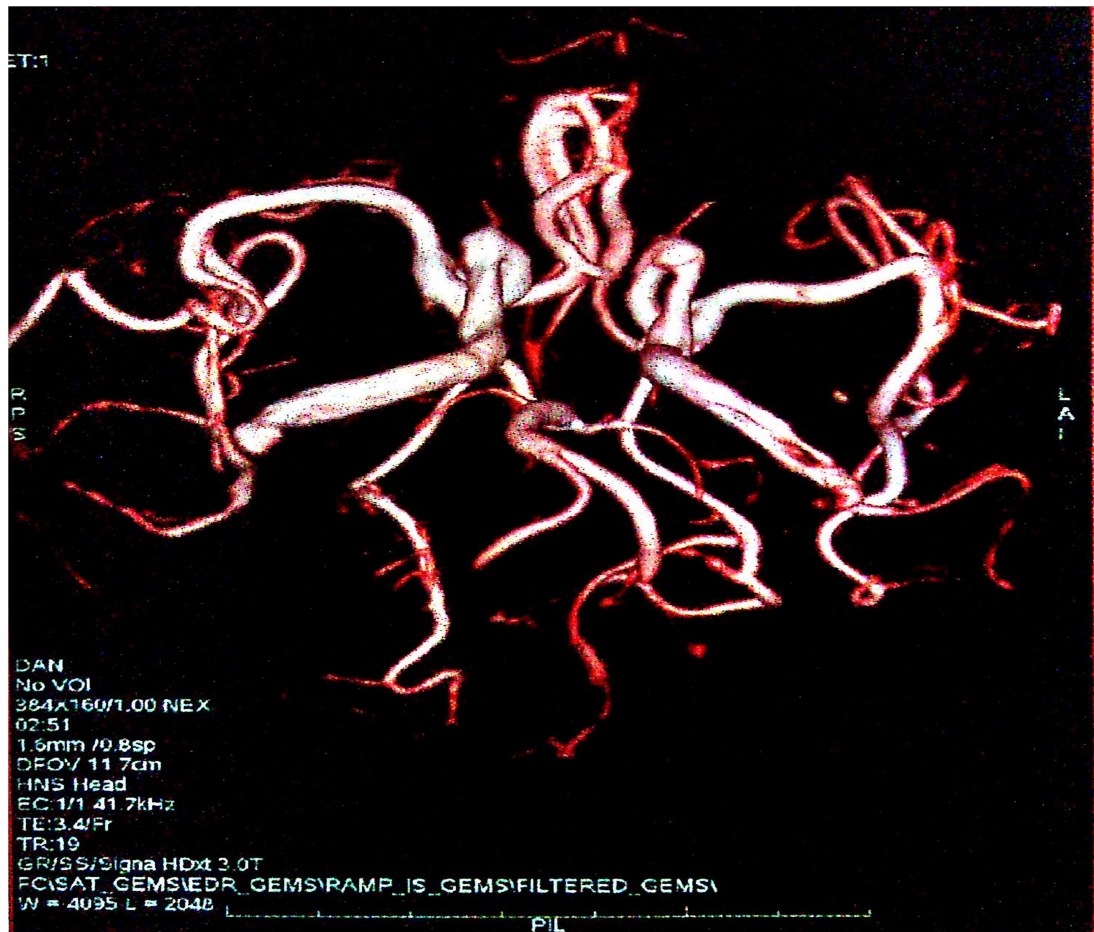


Fig 19: Hypoplasia of left Posterior cerebral artery.

### **III. INCIDENCE OF ACCESSORY VESSELS:**

In the present study, no case of absent vessels were reported.

### **IV. INCIDENCE OF ANOMALOUS ORIGIN:**

<b>Name of the vessel</b>	<b>No. of abnormal origin</b>	<b>Percentage (%)</b>
<b>Anterior cerebral artery (A1)</b>	-	-
<b>Anterior communicating artery</b>	-	-
<b>Posterior cerebral artery(P1)</b>	<b>4</b>	<b>25</b>
<b>Posterior communicating artery</b>	-	-

Table 10: showing incidence of abnormal origin of vessels out of 50 specimens.

The fetal origin of posterior cerebral artery from internal carotid artery was found in 4 cases with a percentage of 25%. The other arteries do not show any abnormal origin.

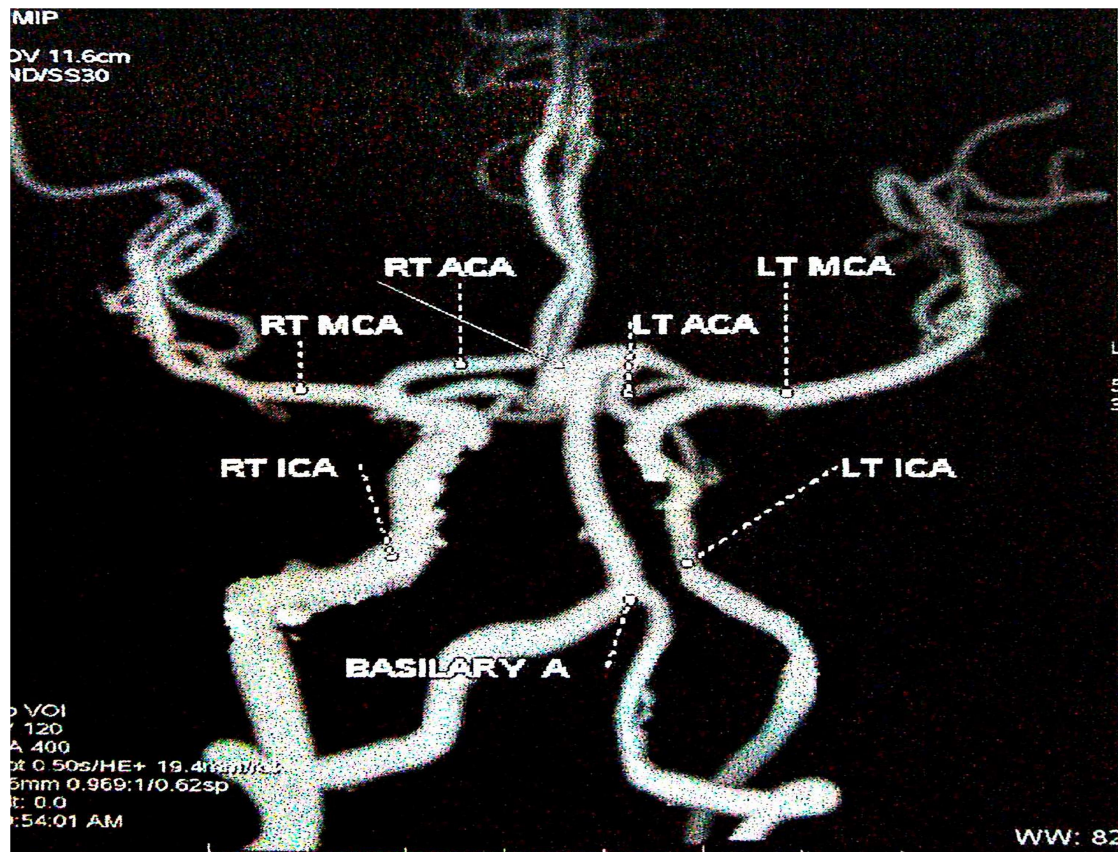


Fig 20.: Left fetal origin of posterior cerebral artery.



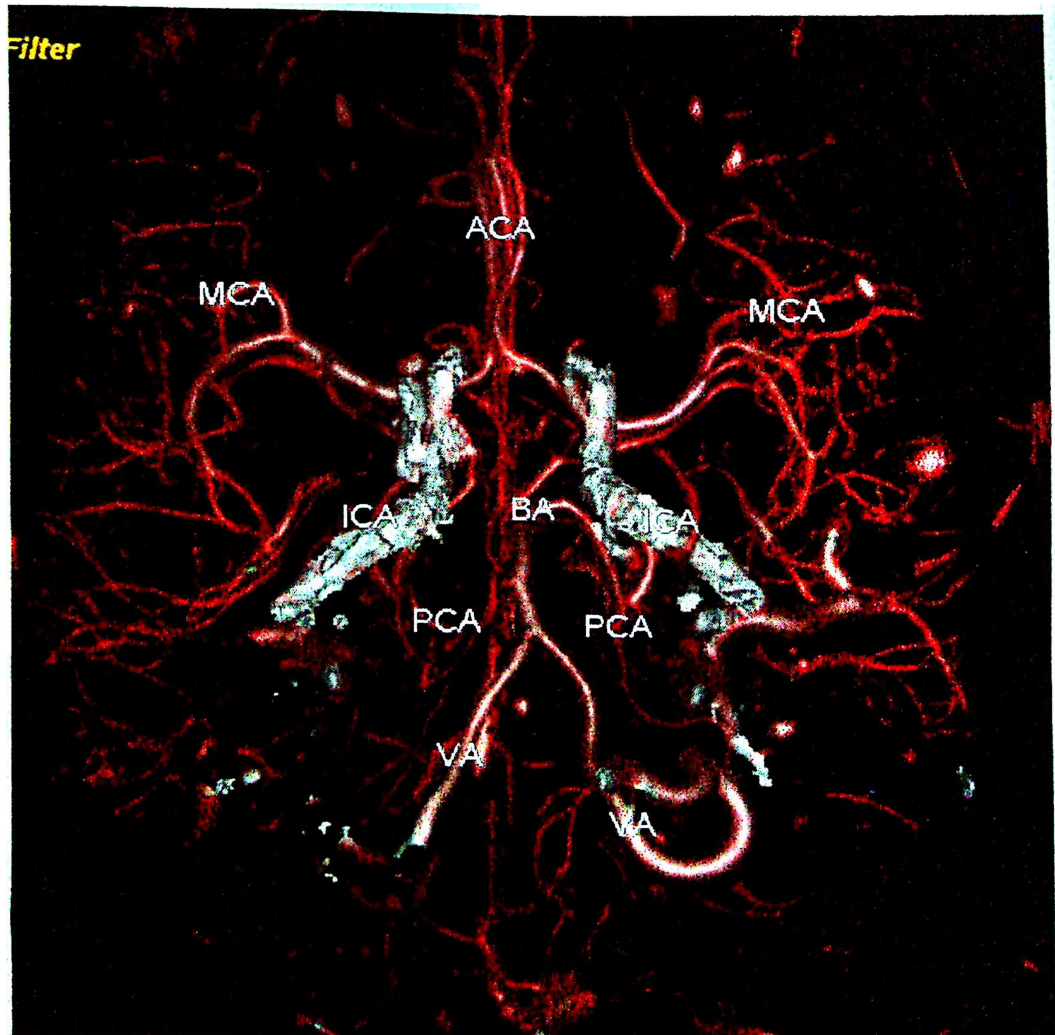


Fig 21: Right sided Fetal origin of posterior cerebral artery.



Fig 22.: Radiological image showing bilateral fetal type of Posterior cerebral artery.

**V) INCIDENCE OF VARIATION IN ANTERIOR AND POSTERIOR PART OF THE CIRCLE OF WILLIS:**

<b>No./Percentage</b>	<b>Anterior circle</b>	<b>Posterior circle</b>
<b>Number of cases</b>	<b>7</b>	<b>9</b>
<b>Percentage</b>	<b>43.75%</b>	<b>56.25%</b>

Table 11: showing percentage of variation in anterior and posterior part of circle.

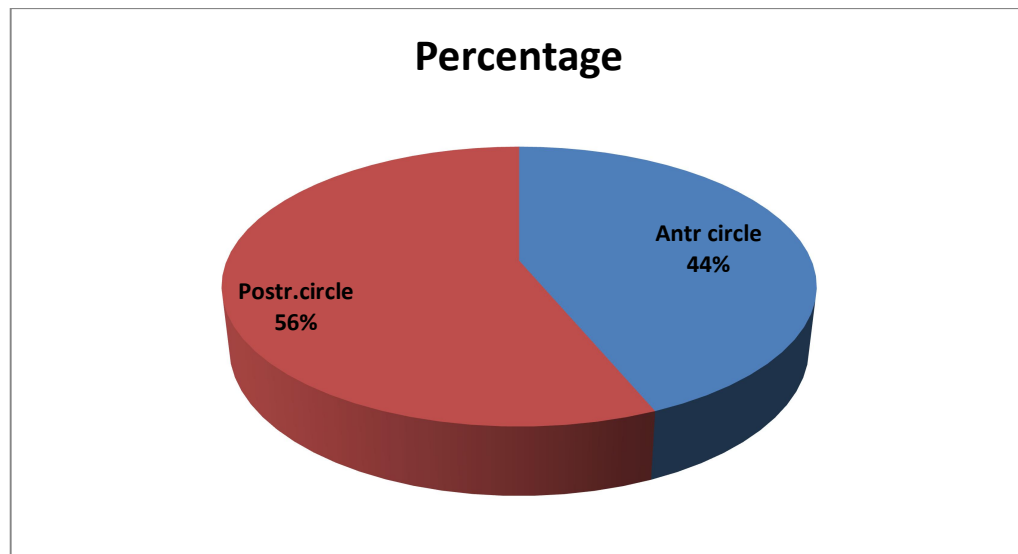


Fig 23: Pie chart showing graphical representation of incidence of variations of anterior and posterior circle.

## VI. VARIATION IN INDIVIDUAL VESSELS:

<b>Name of the vessels</b>	<b>Absent vessels</b>	<b>Hypoplasia</b>	<b>Accessory vessels</b>	<b>Anomalous origin</b>	<b>Percentage (%) (50 specimens)</b>
Anterior cerebral artery	-	7	-	-	43.75
Anterior communicating Artery	-	-	-	-	-
Posterior cerebral artery	-	4	-	4	50
Posterior communicating Artery	-	1	-	-	6.25

Table 12: showing overall incidence of variation of individual vessels.

The overall variation in the anterior part of the circle is 43.75% and of the posterior circle is 56.35%. The common variation seen radiologically is hypoplasia of anterior cerebral artery followed by posterior cerebral artery. The anomalous origin of fetal posterior cerebral artery arising from internal carotid artery was seen in 4 cases with a percentage of 25%.(table 12)

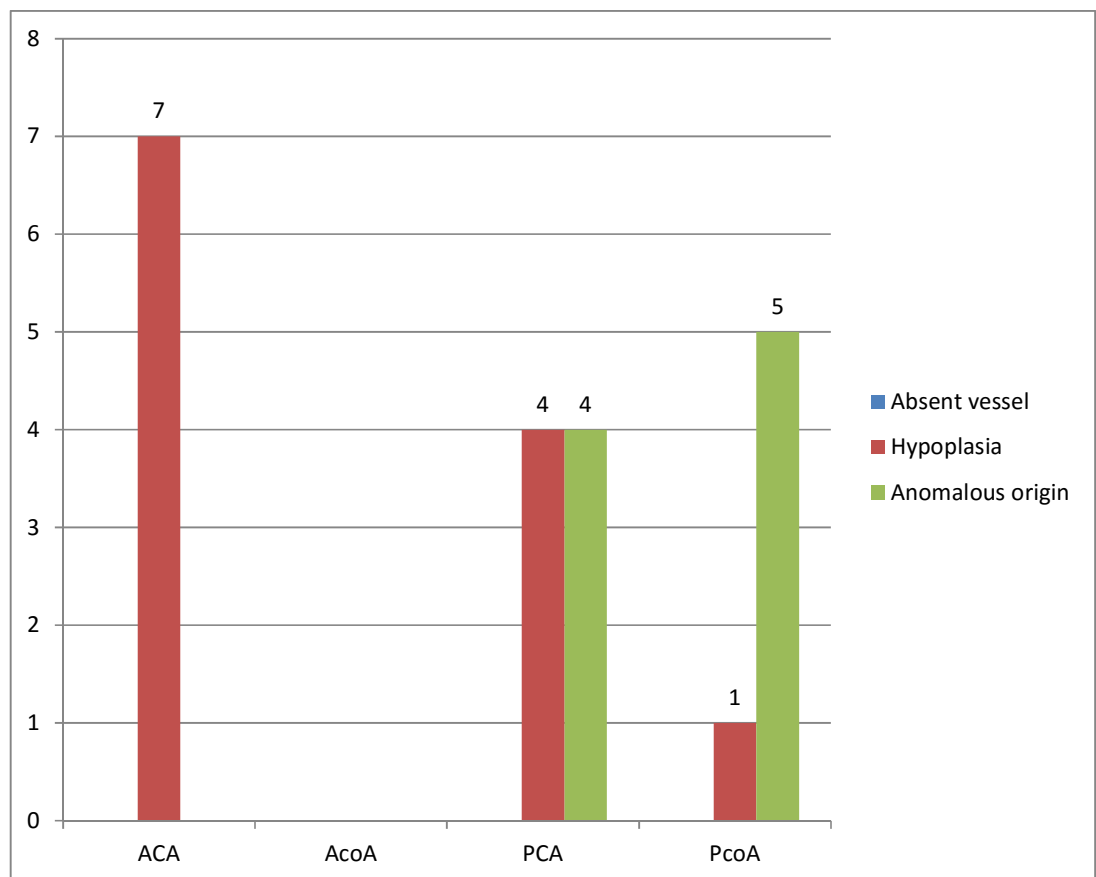


Fig 24: Column showing graphical representation of incidence of variations among cerebral and communicating vessels.

<b>Name of the variations</b>	<b>Percentage of total variations</b>
<b>Absent vessels</b>	-
<b>Hypoplasia</b>	<b>75</b>
<b>Accesory vessels</b>	-
<b>Anomalous origin</b>	<b>25</b>

Table 13: showing percentage of total variations.

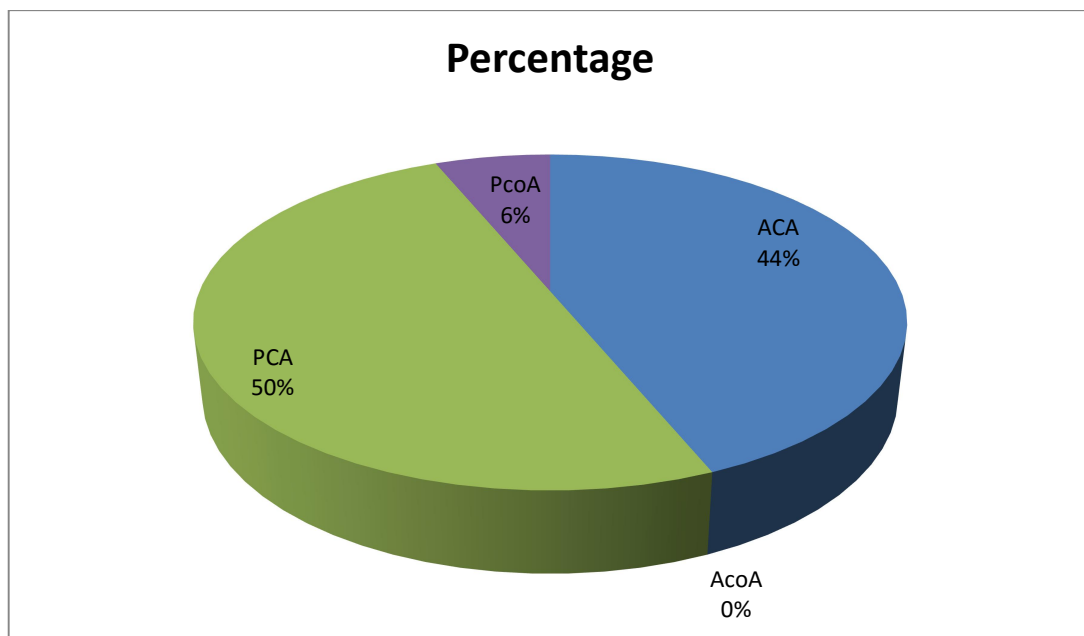


Fig 25: Pie chart showing percentage of individual variation in the circle of vessels.

The most common variation among vessels forming the Circle of Willis is the hypoplasia with a percentage of 75%. The next common variation is presence of anomalous origin in 25% of specimens. Among all the four vessels, posterior cerebral artery showed more variations (50%). Hypoplasia of anterior cerebral artery is 43.75%. followed by posterior cerebral artery with 25% and posterior communicating artery with 6.25%.

## DISCUSSION

1. The Circle of Willis and its branches are subjected to numerous variations. The variations not only differ from person to person but also on the right and left side of the same individual. The role of arterial circle is to equalize the pressure and under normal condition, little interchange of blood takes place along the anastomotic channel due to equality of blood pressure. In case of occlusion, the arterial circle tends to equalize the pressure, thereby maintaining the circulation. The prevalence of the typical circle that is “normal text book type” polygon ranges from 5% to 72% (S.Iqbal)<sup>43</sup>. The wide range of variation is due to diversity in defining the criteria used to define hypoplastic vessels. The normal pattern and the variation are tabulated in table no 14 and fig 26.



Author name	Normal pattern(%)	Variations(%)
Alpers et al	52.3%	47.7%
Raja Reddy et al	53.3%	46.7%
Kamath S	56%	44%
Stephen and John	52%	48%
Macchi et al	41%	59%
Raghavendra et al	56%	44%
Hartkamp et al	42%	58%
Present study	58%	42%

Table 14: Comparing the normal and variation percentage with present and other studies.

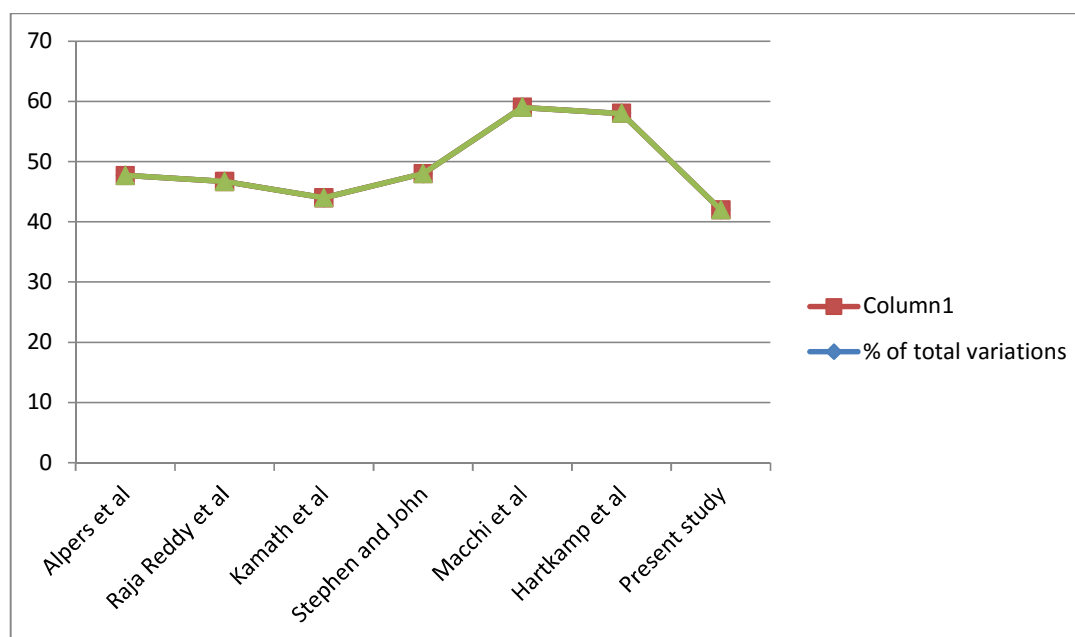


Fig 26:Line diagram comparing the percentage of variations.

2. Raghavendra et al studied about Morphometric variation in the Circle of Willis in 50 adult brain specimens. Among the 50 specimens, 28 cases (56%) had a normal pattern of Circle of Willis while the remaining 22 cases(44%) showed variations. The common variation reported is the hypoplastic posterior communicating artery with a percentage of 31.8%. Of the 22 cases, 7 variations were seen in the anterior circulation and 15 variations were seen in the posterior circulation. In this study, variations in anterior circle was found in 7 cases and 14 cases showed variations in posterior circle (Table 15)

Variations	Raghavendra et al (percentage)	Present study (percentage)
Anterior circle	31.8	33.34
Posterior circle	68.2	66.67

Table no 15: Comparing the present study with that of other study.

Thus the finding of the present study is comparable with that of Raghavendra et al .

The findings of the present study were also comparable with the study done by Alpers et al, Raja Reddy et al, Kamath S, Stephen and John et al etc.

3. S.Iqbal studied about the Anatomical variation of the Circle of Willis in adult Human brain. The parameters included were the morphological variations of the arteries forming the Circle of Willis. In their study, majority of the circle showed variations(52%). Hypoplasia was the most common variation and was found in 24% of the brain specimens. Accessory vessels in the form of duplication or triplication of anterior communicating artery were seen in 12% of the circle. In this study, 42% of the brain specimens showed variation. The parameters include completeness of the circle, symmetrical, normal caliber and polygonal in shape. In the present study, hypoplasia was a common variation seen in 26%,which is comparable to the previous study done by S.Iqbal. The other variations are tabulated.

Variations	S.Iqbal et al (in percentage)	Present study (in percentage)
Absent vessels	6%	2%
Hypoplasia	24%	26%
Accessory vessels	12%	10%
Abnormal origin	10%	4%

Table no 16: Comparing percentage of variations in both studies.

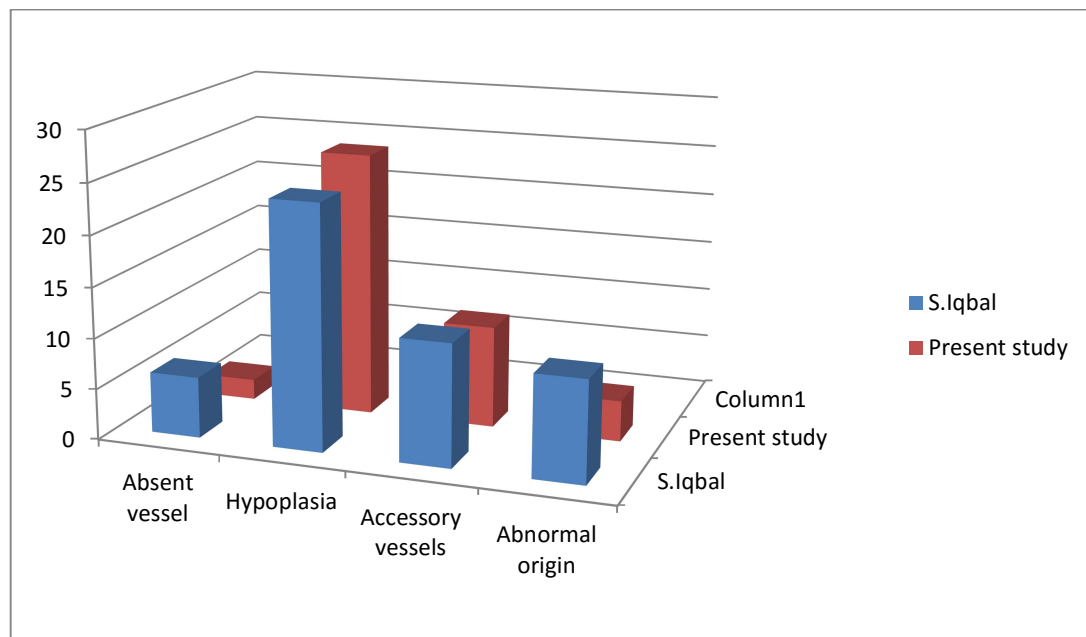


Fig 27: Column comparing percentage of variations between S.Iqbal and present study.

4. Hypoplasia or attenuation of either the cerebral or the communicating vessel were found to be common among the variations. Hypoplasia were found in 26% of the present study and were common among all other variation. Alpers et al reported an incidence of 27%, Kamath with an incidence of 24% and Fetterman and Moran with an incidence of 23%. The following table compare the incidence of hypoplasia of the present study with the other studies.

Name of the author	PCOA	PCA (P1 segment)	ACOA	ACA(A1 segment)
Alpers et al	22%	-	3%	2%
Riggs & Rupp	53%	27.7%	9.25%	11.97%
Kamath	10%	-	2%	2%
Present study	38.09%	14.2%	4.7%	4.7%

Table No.17: Comparing the incidence of hypoplasia among different vessels.

The wide range of variation is due to the different criteria used to measure hypoplastic vessels. Hypoplasia were more prominent in the posterior portions of the Circle of Willis. This finding in the present study is comparable with other studies.

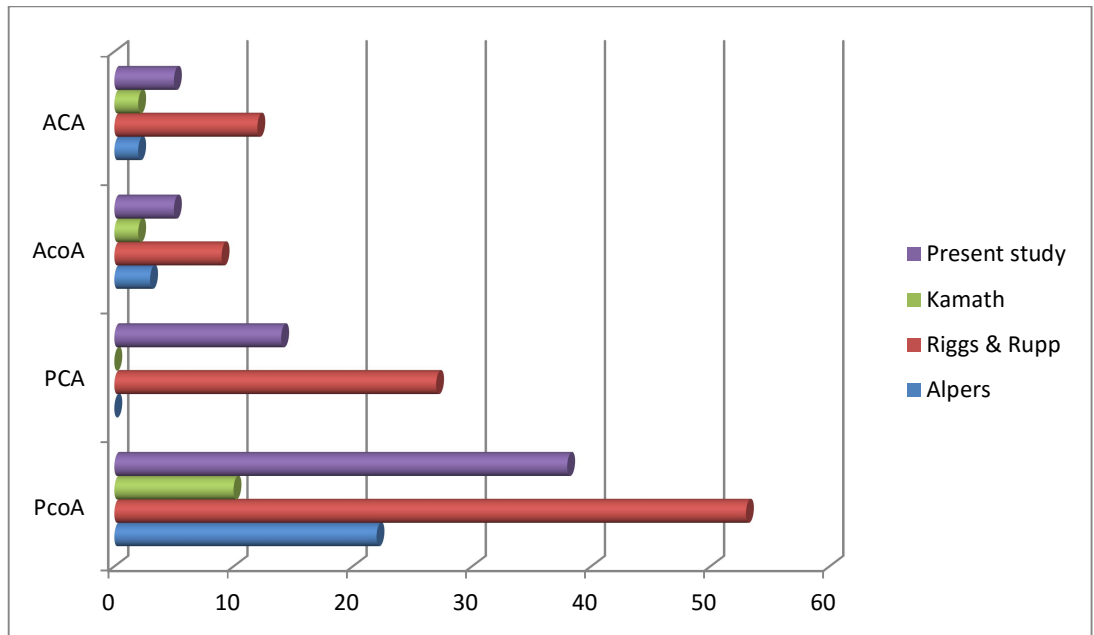


Fig 28: Bar diagram comparing incidence of hypoplasia.

- Accessory vessels in the form of duplication or triplication were found in the Circle of Willis. Among the accessory vessels, the incidence of duplication of Anterior communicating artery were 19.04% and the anterior cerebral artery were 4.7% in a total of five cases. The accessory vessels were not seen in posterior circulation. Apart from two normal anterior cerebral artery, it is also accompanied by a midline third anterior cerebral artery. This finding were comparable with S.Iqbal et al.

5. The embryonic origin of the posterior cerebral artery from the internal carotid artery were found in 9.52% of the circle. Such a vessel is connected to the basilar artery by a small communicating artery.

Name of the author	Incidence of embryonic origin of PCA from ICA(%)
S.Iqbal	10%
Riggs & Rupp	22%
Alpers et al	15%
Milenkovic et al	21%
Present study	9.52%

Table No.18. Comparing the incidence of anomalous origin.

The anomalous origin were seen in 2 cases (9.52%). This study was comparable with S.Iqbal, Alpers et al.

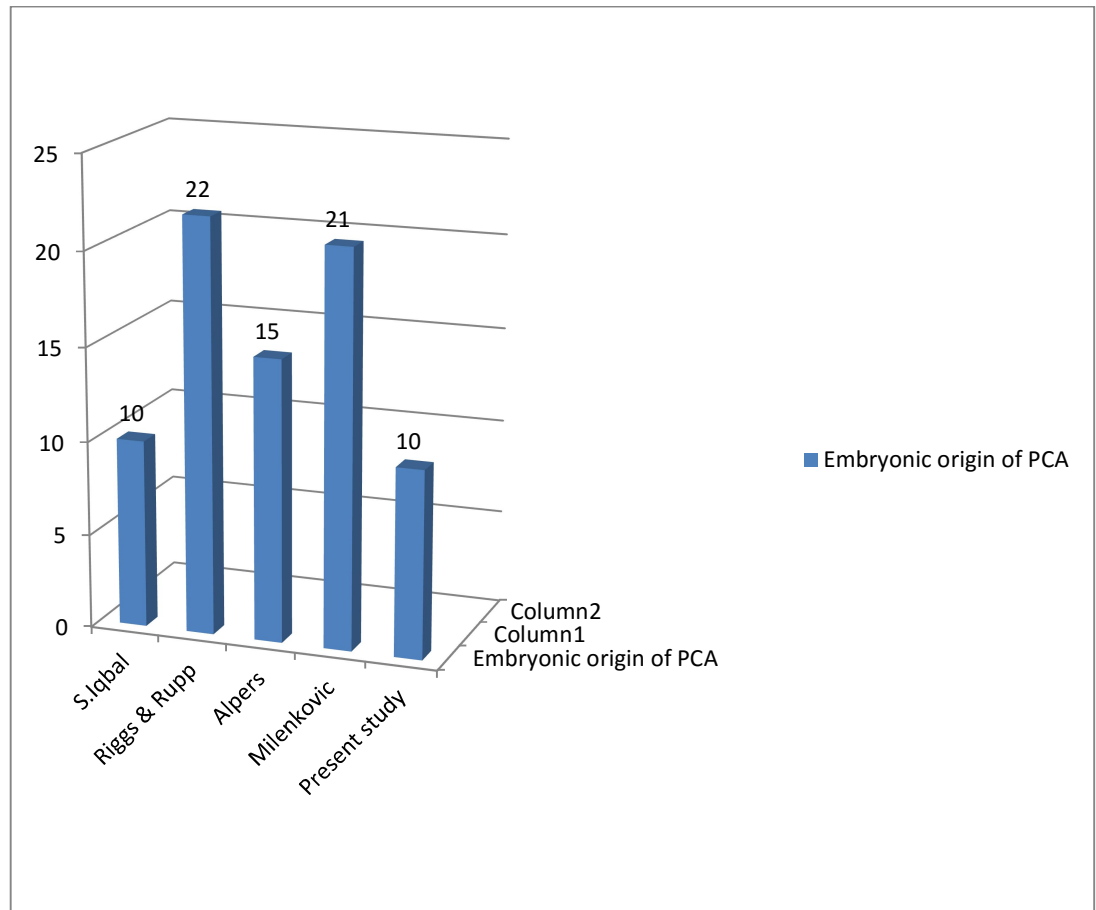


Fig 29. Column comparing embryonic origin of posterior cerebral artery.

6. The least common anomaly of the Circle of Willis was the absence of one of the cerebral or the communicating vessels. In the present study, absence of posterior communicating artery were seen in one case with a percentage of 4.7%. The reported incidence of absent vessels in the Circle of Willis in normal brain ranges from 0.6% (Alpers) to 17%(Windle BCA). The absent vessel is not seen in anterior part of the circle. Fawcett and Blachford reported an



incidence of 3.8% of absent vessels of posterior communicating arteries.

7. Cerebrovascular diseases such as stroke, thromboembolism, aneurysms together with their signs and symptoms depend upon the variations of the anatomical pattern of the Circle of Willis. The main collateral blood flow is through the communicating arteries and obstruction of the collateral pathway determines the severity of hemodynamic impairment(Yu-Ming Chuang). The state of circle becomes important in determining the adequacy of the brain circulation.
8. For the radiological study, Magnetic Resonance Angiography has been used. The total number of images taken for the study is 50. 34 cases were found to be normal and the remaining 16 cases showed abnormal type of Circle of Willis. The abnormal circle either showed asymmetrical pattern, incomplete, or abnormal caliber. The variations pertaining only to the Circle of Willis were taken and was seen in 16 cases. There are other variations present in the study but were not taken owing to the objective of the study. Those variations include vertebral hypoplasia, stenosis /narrowing of internal carotid artery, ectasia of internal carotid artery and vertebrobasilar fenestrations(fig 30,31,32)



Fig no30: Right side Vertebral artery hypoplasia along with hypoplasia of Right ACA.

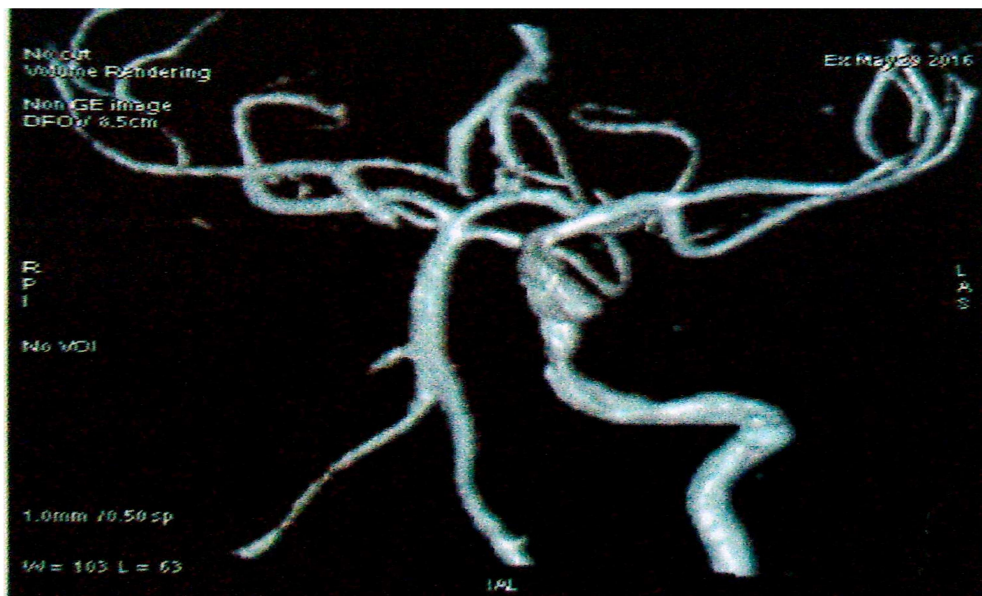


Fig no.31: Stenosis of right internal carotid artery.

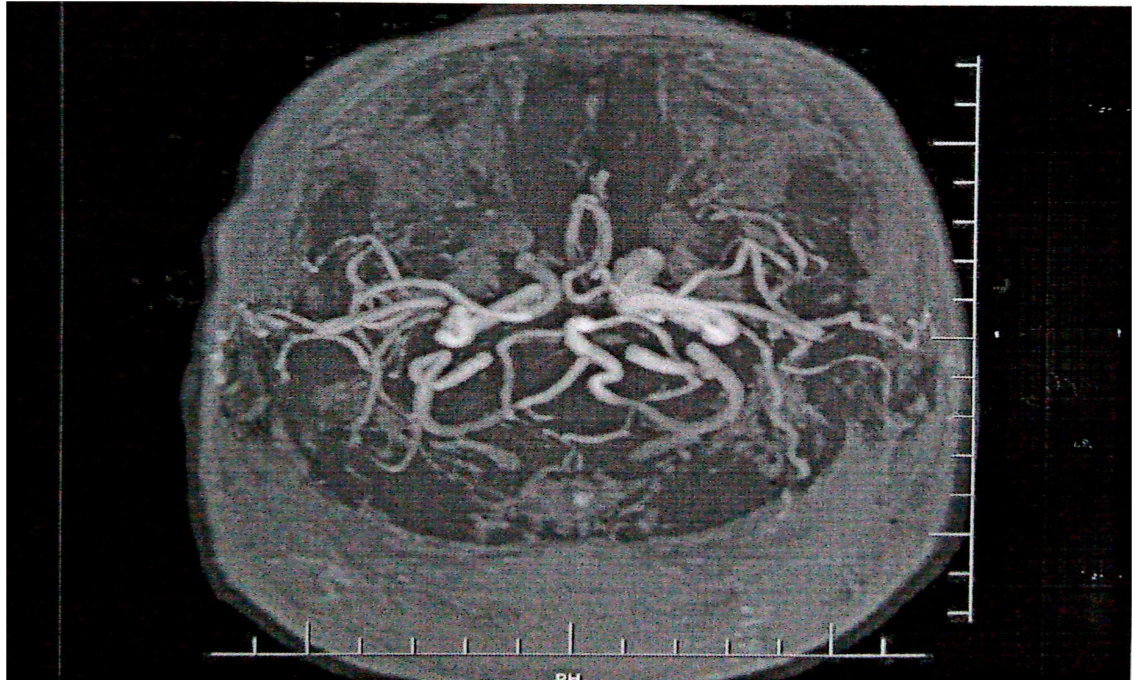


Fig no32: Showing ectasia of left internal carotid artery

Variations	Total no.of cases
Variations in the Circle of Willis	16
Vertebral artery hypoplasia	5
Stenosis/Narrowing of internal carotid artery	2
Ectasia of internal carotid artery	1
Vertebrobasilar fenestrations	1

Table no.19: Showing the incidence of other variation in the present study

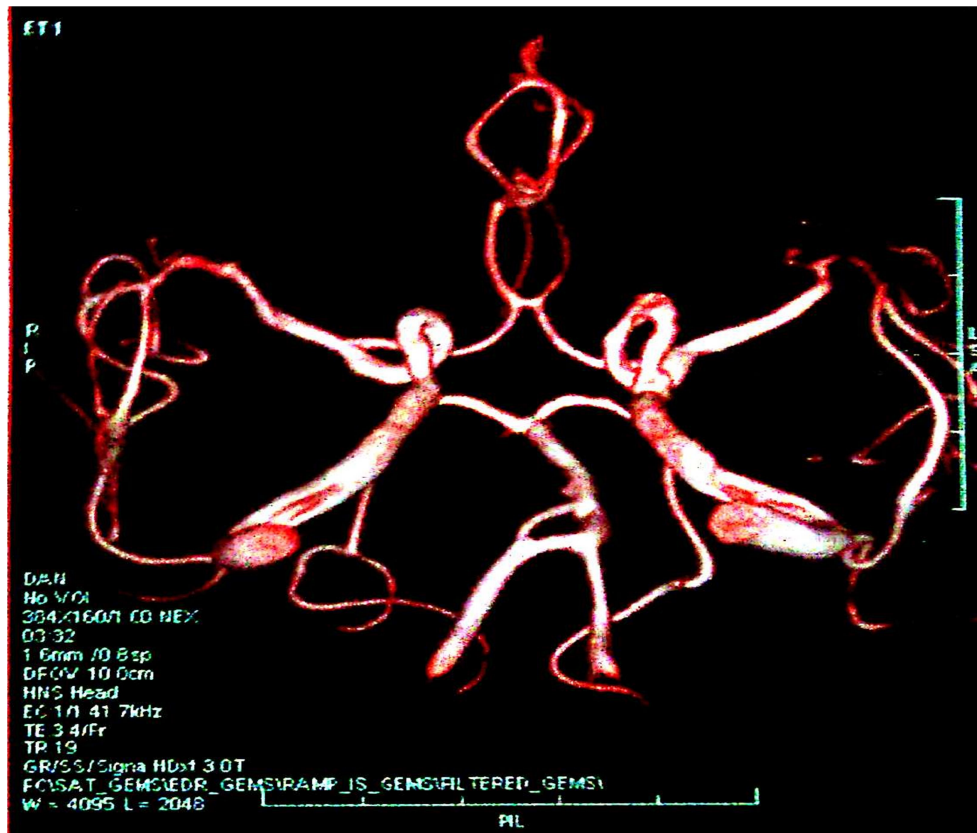


Fig no33: Radiological image showing vertebrobasilar fenestrations.

9. The patients whose radiological images taken for the study were admitted with variety of neurological symptoms including stroke, focal muscular weakness, hemiparesis, hemiplegia etc. The outcome of the neurovascular injury depends on the presence or absence of collateral flow. The availability of these collaterals depends upon the normal pattern of Circle of Willis (Kalula N.T). Ability of the Circle of Willis to redistribute blood flow depends on its component vessels, (Miralles et al).



10. The incidence of normal pattern of Circle of Willis radiologically shows wide variations among different studies. In the present study, out of 50 radiological images, 16 cases showed variation in the pattern of Circle of Willis with an percentage of 32%. The same parameters of the other study were compared in Table no 20.

Study	Brains examined	Normal pattern(%)
Krabbe-Hartkamp et al	150	42%
Biswajeethsaikia et al	70	24.18%
Haripriya and Melani	50	32%
Present study	50	68%

Table no 20: Comparing the normal incidence of other studies with the present study.

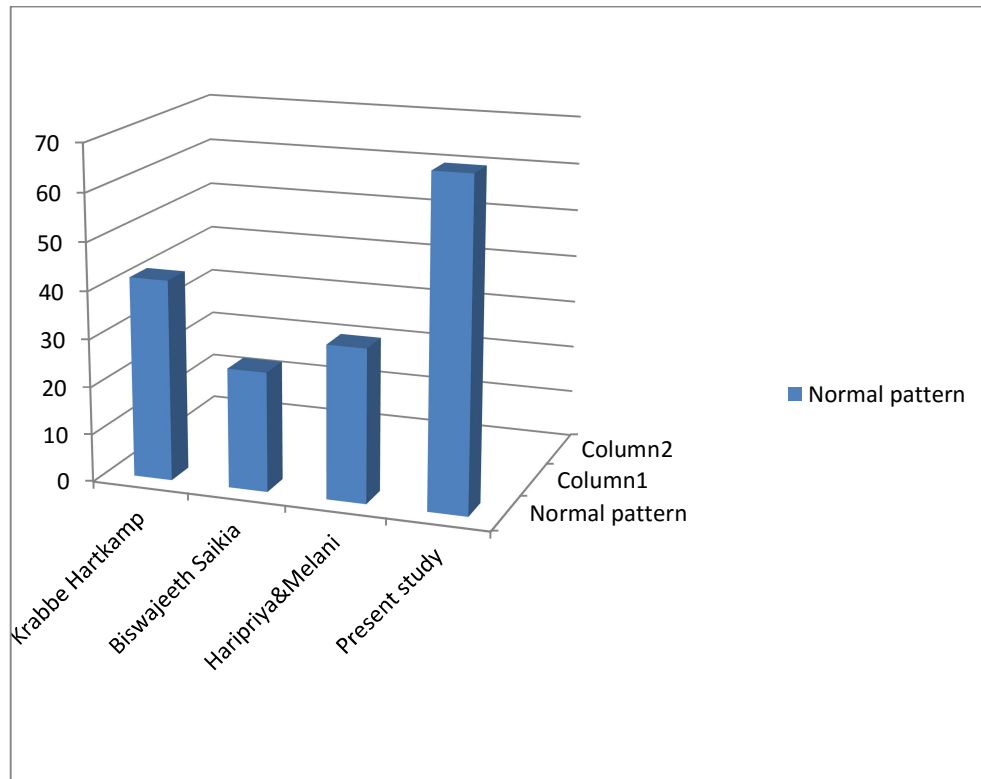


Fig 34; Column comparing normal pattern of Circle of Willis.

The prevalence of complete Circle of Willis was seen in 68% of the present study.

## CONCLUSION

The arterial Circle of Willis was studied and analysed as per the parameters taken by dissection method and from radiological images.

The results were charted out, statistically analyzed and correlated with the finding of the existing studies. The findings are summarized below.

1. The normal parameter like complete formation, shape, normal caliber of vessels and symmetrical Circle of Willis were found in more than 55% of cases.
2. The variations in the Circle of Willis like absent vessels, hypoplasia of vessels and accessory vessels also found.
3. The posterior part of the circle were found to have more variation (66.67%) than the anterior part of the circle (33.34%) involving the posterior cerebral artery and posterior communicating artery.
4. Among the variations found, hypoplasia was the most common variation and hypoplasia was seen more commonly in posterior communicating artery followed by posterior cerebral artery .
5. The other variations like anomalous origin of posterior cerebral artery was also found.

A thorough knowledge about the normal anatomy of Circle of Willis and its variations like hypoplasia, attenuation of vessels and anomalous origin is necessary for clinicians, neuro surgeons, vascular surgeons and radiologist. This will help them to diagnose the diseases and to plan for further management to perform correct interventional procedures.



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